Westinghouse Technology Manual

Section 3.2

Reactor Coolant System

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3.2 REACTOR COOLANT SYSTEM

Learning Objectives:

1. State the purpose of the reactor coolant system.

2. List in flow path order and state the purpose of the following major components of the reactor coolant system:

    a. Reactor vessel,
    b. Steam generator, and
    c. Reactor coolant pump.

3. List and state the purpose of the following reactor coolant system penetrations:

    a. Hot leg
        1. Pressurizer surge line,
        2. Resistance temperature detector, and
        3. Residual heat removal system suction.

    b. Intermediate (crossover) leg
        1. Chemical and volume control system letdown connection and
        2. Elbow flow taps.

    c. Cold leg
        1. Pressurizer spray line,
        2. Resistance temperature detector,
        3. Common emergency core cooling system connection for residual heat removal, safety injection, and cold leg accumulators,
        4. High head injection, and
        5. Chemical and volume control system charging.

4. Describe the flow path through the steam generator for both the reactor coolant system and steam side.

5. State the purpose of the following components of the reactor coolant pump:

    a. Thermal barrier heat exchanger,
    b. Shaft seal package,
    c. Flywheel, and
    d. Anti-reverse rotation device.

6. State the purpose of the pressurizer and the following associated components:

    a. Code safety valves,
    b. Power operated relief valves,
    c. Power operated relief valves block valves,
    d. Pressurizer relief tank,
    e. Pressurizer spray valves, and
    f. Pressurizer heaters.

3.2.1 Introduction

The purpose of the reactor coolant system (RCS) is to transfer the heat produced in the core to the steam generators (S/Gs), where steam is produced for the turbine generator. The RCS is a closed-cycle, high pressure, fluid system that provides the second barrier to prevent an inadvertent release of radioactivity to the containment. Any breach of the fuel cladding (the first barrier against a release) will be contained within the boundary of the surrounding RCS (with the third barrier being the containment building). The RCS also provides a means of controlling pressure in the system to prevent departure from nucleate boiling. Since a pressurized water reactor is a dual cycle plant with only limited nucleate boiling allowed in the reactor core, the RCS (primary cycle) must circulate the heated, high pressure reactor coolant to the S/Gs and back to the reactor.

3.2.2 General Description

The RCS consists of several similar heat transfer loops connected in parallel to the reactor vessel (Figure 3.2-1). Each loop contains a S/G and a reactor coolant pump (RCP). The pressurizer is connected to one of the loops' hot leg. A flow diagram of a typical RCS is shown on Figure 3.2-2.

3.2.3 Component Description

RCS design data are shown in Table 3.2-1.

3.2.3.1 Pressurizer

The pressurizer, which acts as a surge volume for the RCS, provides a point in the RCS where liquid and vapor can be maintained in equilibrium under saturated conditions for control of system pressure. This is the only point in the RCS where reactor coolant is maintained at saturation temperature.

The pressurizer (Figure 3.2-3) is a vertical, cylindrical vessel with hemispherical top and bottom heads. It is constructed of carbon steel with stainless steel clad on all surfaces in contact with reactor coolant. Electrical heaters are installed through the bottom head while the spray nozzle, relief valve, and safety valve connections are located in the top head of the vessel.

Load changes cause the reactor coolant temperature to change, which then causes the coolant to expand and contract due to density changes. As the coolant expands, it will cause and "insurge" into the pressurizer and an "outsurge" as it contracts. The pressurizer is designed to accommodate these insurges and outsurges. The surge line, which is attached to the bottom of the pressurizer, connects the pressurizer to one of the reactor coolant hot legs (Figure 3.2-2).

During an insurge, caused by an increase in reactor coolant temperature, pressure tends to increase as the steam volume is forced to occupy a smaller space. The spray system directs water from two loop cold legs to the pressurizer spray nozzle, condensing some of the steam, thus limiting the pressure increase to prevent lifting the pressurizer power operated relief valves. The spray valves are modulated by the pressurizer pressure control system (Chapter 10.2).

During an outsurge, caused by a decrease in reactor coolant temperature, pressure tends to decrease as the water level is lowered and the steam expands due to the larger steam volume. This lowering of pressure will cause some of the water in the pressurizer to flash to steam since the water is above the saturation temperature for the lower pressure. The pressurizer heaters will be energized by the pressurizer pressure control system (Chapter 10.2) to return system pressure to normal (2235 psig).

To limit system pressure if a transient is beyond the capability of the spray system, relief and safety valves are provided. The relief valves are air operated and receive an actuation signal from pressurizer pressure instrumentation. Their purpose is to prevent reactor pressure from activating the high pressure reactor trip or from reaching the setpoint of the code safety valves. Remotely operated block valves are provided to isolate the power operated relief valves if excess leakage occurs. The safety valves are self-actuating and are designed to limit reactor pressure to less than design (2500 psia) plus 10% (2750 psia). The safety and relief valves discharge into a pressurizer relief tank through an underwater sparger or spray ring.

3.2.3.2 Steam Generator

A steam generator (Figure 3.2-4) is provided in each reactor coolant loop. Reactor coolant water flows from the reactor, through the loop hot leg, to the tube (primary) side of the S/G, where heat is transferred to the shell (secondary) side to produce steam. The coolant then flows through the intermediate leg to the suction of the RCP and is pumped through the cold leg to the reactor inlet.

The S/Gs are vertical, shell and U-tube heat exchangers with integral moisture separation equipment. The reactor coolant enters the hemispherical bottom head through the inlet nozzle, flows through the U-tubes, and exits through the outlet nozzle. The bottom head is divided into inlet and outlet plenums by a vertical partition plate extending from the tube sheet to the head.

The secondary flow path through the S/G begins with feedwater from the feedwater and condensate system (Chapter 7.2) entering the S/G through a feedring. The feedwater exits the feedring through inverted J-tubes and combines with recirculation flow from the moisture separators. The combined flow then travels down the annulus between the tube wrapper and S/G shell. At the bottom of the tube wrapper, the feedwater turns and flows up past the outside of the steam generator tubes, where the feedwater is heated to saturation as it picks up heat from the reactor coolant across the tubes.

The moisture laden steam flows upward through swirl vane and chevron moisture separating equipment to the steam outlet nozzle at the top of the steam generator. The steam generators are designed to produce, at rated steam flow, saturated steam with less than 0.25 percent moisture by weight.

The materials of construction consist mainly of carbon steel with all surfaces in contact with reactor coolant fabricated or clad with corrosion resistant material. The heat transfer tubes are constructed of inconel, the tube sheet is clad with inconel, and all other surfaces on the primary side are clad with stainless steel.

3.2.3.3 Reactor Coolant Pumps

Each reactor coolant cold leg contains a vertical, single stage, centrifugal pump employing a controlled leakage shaft seal assembly (Figure 3.2-5).

Reactor coolant is drawn up into the pump impeller, out through the diffuser, and discharged through a discharge nozzle in the side of the casing. The impeller can be removed from the pump casing for maintenance and inspection without removing the casing from the piping. All parts of the pump in contact with reactor coolant are stainless steel or equivalent corrosion resistant material.

A controlled leakage seal assembly is employed to restrict reactor coolant leakage along the pump shaft. A portion of the charging flow from the chemical and volume control system (CVCS) is injected into the reactor coolant pump (RCP) between the impeller and the seal. Part of this injection flow is directed down the pump shaft past the thermal barrier and heat exchanger into the RCS to serve as a buffer to keep high temperature reactor coolant out of the upper portion of the pump. The remainder of the injection water flows up the shaft to provide cooling and lubrication for the pump radial bearing and shaft seal assembly.

Component cooling water (CCW) is supplied to the motor bearing oil coolers and the thermal barrier cooling coil. The thermal barrier cooling coil ensures that the reactor coolant, which would flow up the shaft on a loss of seal injection flow, is cooled before it reaches the pump radial bearing and seal area.

To prevent a sudden loss of RCS flow when an RCP is deenergized, a flywheel (Figure 3.2-8) is provided on the motor shaft to extend the flow coastdown time. A ratchet device is also provided to prevent reverse rotation of an idle RCP. If the pump is allowed to rotate in reverse, backflow through that idle loop increases and is not available for core cooling. Reverse rotation also causes high starting current to be applied to the motor when the pump is restarted.

3.2.3.4 Reactor Coolant Piping

The reactor coolant piping and fittings which make up the loops are austenitic stainless steel. All smaller piping which comprises part of the RCS pressure boundary, such as the pressurizer surge line, spray line, relief line, loop drains, and connecting lines to other systems, are also stainless steel. All joints and connections are welded, except for the pressurizer relief and code safety valves, where flanged joints are used. Thermal sleeves are provided at various penetrations as appropriate.

3.2.3.5 Valves

All valves which are in contact with reactor coolant are constructed primarily of stainless steel. RCS valves three inches and larger, because they contain radioactive fluid and operate above 212°F, are provided with double-packed stuffing boxes and intermediate lantern gland leakoff connections. All throttling valves are provided with similar steam leakoff connections. Leakage to the containment for these valves is essentially zero.

Some plants are also provided with reactor coolant loop isolation valves which can be used to isolate a reactor coolant loop for maintenance. The valves are motor operated gate valves taking approximately three to five minutes to open or close. An extensive interlock system is supplied with these valves to ensure that a cold or deborated loop is not opened to the reactor causing a potential reactivity addition accident.

3.2.3.6 Miscellaneous Loop Penetrations

Each reactor coolant loop (Figure 3.2-7) is provided with penetrations from the emergency core cooling systems. In each loop cold leg is a high head safety injection penetration from the discharge of the charging pumps. Also provided to each cold loop cold leg is a penetration from the cold leg accumulators. The residual heat removal (RHR) pumps and safety injection pumps also discharge into the cold leg through the accumulator penetration. Piping is also provided to allow certain portions of the emergency core cooling systems to discharge into the loop hot legs.

An RHR suction line is attached to one of the loop hot legs with the pressurizer surge line connection made to another hot leg. Sample taps are also connected to two of the loop hot legs.

Cold leg penetrations include the letdown to the CVCS and the charging line from the CVCS. Two connections are provided for the pressurizer spray lines.

Loop penetrations common to all loops are:

- Hot and cold leg drains,

- Hot and cold leg RTD wells, and
- RCS elbow flow taps.

3.2.3.7 Instrumentation

Each reactor coolant loop (Figure 3.2-7) is provided with flow detectors of the elbow type. These elbow flow detectors allow the measurement of the flow induced differential pressure without introducing a pressure drop in the loop.

Temperature indication for both the hot leg and cold leg is accomplished by resistance temperature detectors (RTDs) located in the loops. These temperature detectors are used for indication, control, and reactor protection signals.

Pressurizer instrumentation includes both level and pressure detectors. Pressurizer pressure is sensed from the steam space in the pressurizer.

3.2.4 Reactor Coolant Pump Seals

To minimize the leakage of radioactive water from the RCS to the containment building via the shaft of the RCP, it is equipped with a seal package (Figure 3.2-6). The sealing of the shaft is accomplished by the #1 seal, which is a non-contact floating seal. The #1 seal is backed up by the #2 and #3 seals, which are contact type mechanical seals.

In order to understand the operation of the pump seal, several other components must be added to the discussion. First, a lower radial bearing is located below the #1 seal. This bearing is water lubricated and provides alignment of the pump shaft. Next, a thermal barrier and a heat exchanger provide a restricted flow of cooled water to the lower radial bearing and seals in the event that seal injection is not available to the pump. The heat exchanger is cooled by the CCW system. During normal operation, both seal injection and CCW are supplied to each pump.

Approximately 8 gpm of seal injection flow is supplied to the pump from the CVCS. The seal injection flow enters the pump in an area below the lower radial bearing, and the flow is divided into two paths. About 5 gpm flows downward past the thermal barrier and heat exchanger and into the RCS with the remaining 3 gpm flowing up past the lower radial bearing and into the seal package. The 3 gpm flow past the lower radial bearing and #1 seal provide cooling and lubrication for these components. The 3 gpm flow passes through the floating (non-contact) #1 seal where hydrostatic forces maintain a fixed gap between the seal ring and seal runner. Piping connected to the pump above the #1 seal returns the majority of the 3 gpm flow back to the charging pump suction via the seal water heat exchanger. A small amount of flow passes through the #2 and #3 seals for cooling. Leakage past #2 and #3 seals is collected and routed to the reactor coolant drain tank.

CCW to the thermal barrier heat exchanger is not required if seal injection is available. Of particular interest is the flow of water through the pump in the event seal injection is lost. Should this occur, RCS water will flow up through the thermal barrier heat exchanger, which will reduce its temperature. From the thermal barrier, the cool water will lubricate the lower radial bearing and pass through the seal package as described above. This feature allows continued pump operation as long as CCW is available to the heat exchanger.

TABLE 3.2-1
REACTOR COOLANT SYSTEM AND COMPONENT DATA

PARAMETER	VALUE
Design/operating pressure, psig	2485/2235
Hydrostatic test pressure, psig	3107
Height of vessel and closure head, ft-in.	43' 9"
ID/OD of flange sealing flange, in.	172/205
SS clad thickness (minimum), in.	5/32
RCS flow rate, lbm/hr	135×10^6
Total RCS volume, ft^3	12,710
Pressurizer volume, ft^3	1800
Pressurizer heater capacity, Kw	1800
Pressurizer spray rate (maximum), gpm	800
Steam generator height, ft-in.	67' 8"
Steam generator shell OD, in.	175
Steam generator tubes	3388
Steam generator heat transfer area, ft^2	51,500
Steam generator tubes OD/ID, in.	0.875/0.825
Steam flow each steam generator, lbm/hr	3.5×10^6
RCP capacity, each pump, gpm	87,500
RCP capacity, each pump, all running, gpm	66,000
RCP head, ft.	282
RCP starting current, amps	4800
RCP running current, amps	320
RCP horsepower (nameplate), HP	6,000
Reactor coolant cold leg piping ID, in.	27.5
Reactor coolant hot leg piping ID in.	29.0
RCP suction piping ID, in.	31.0
Reactor vessel pressure drop, psi	52
Steam generator pressure drop, psi	30
Reactor coolant loop piping pressure drop, psi	9.5

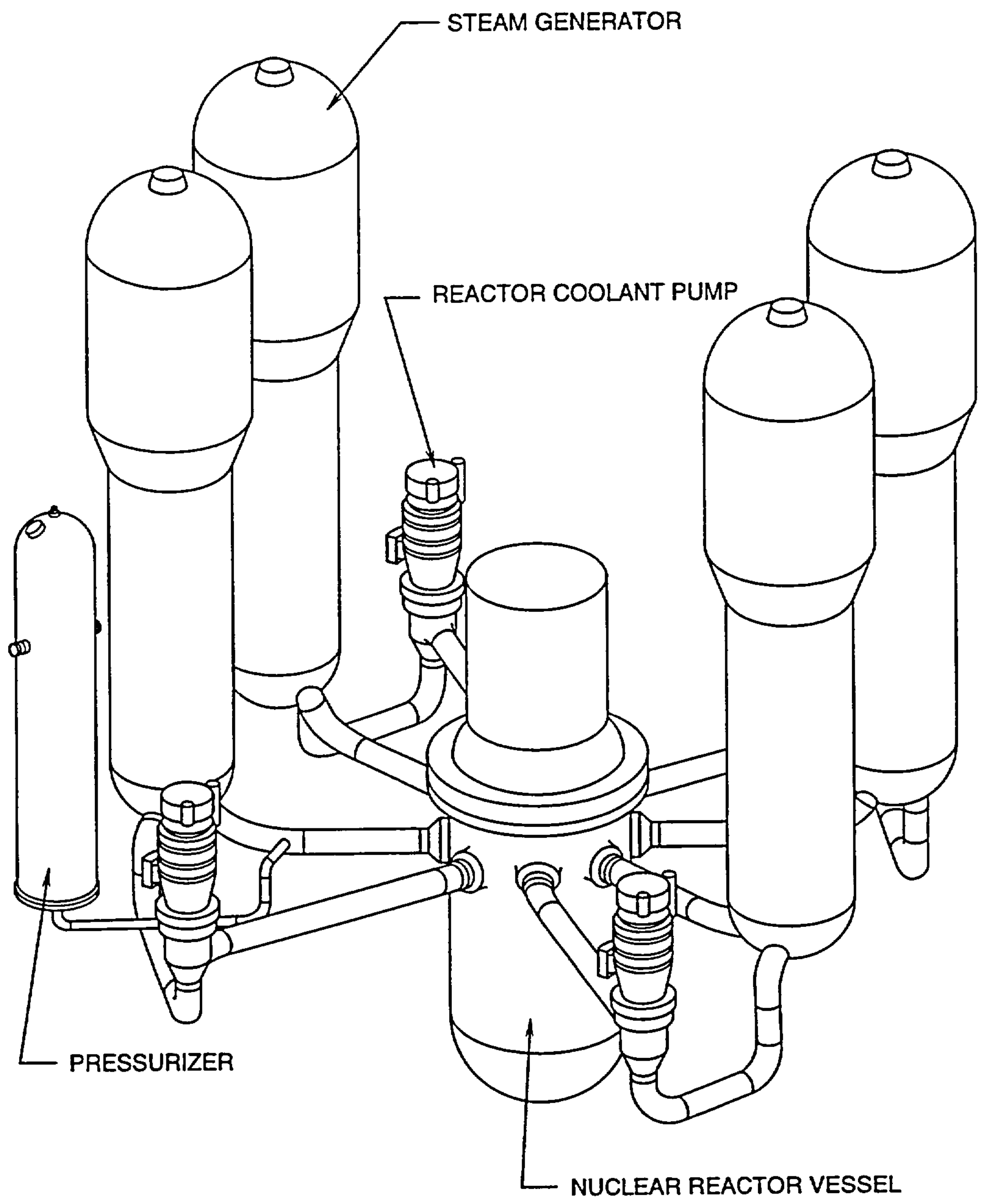
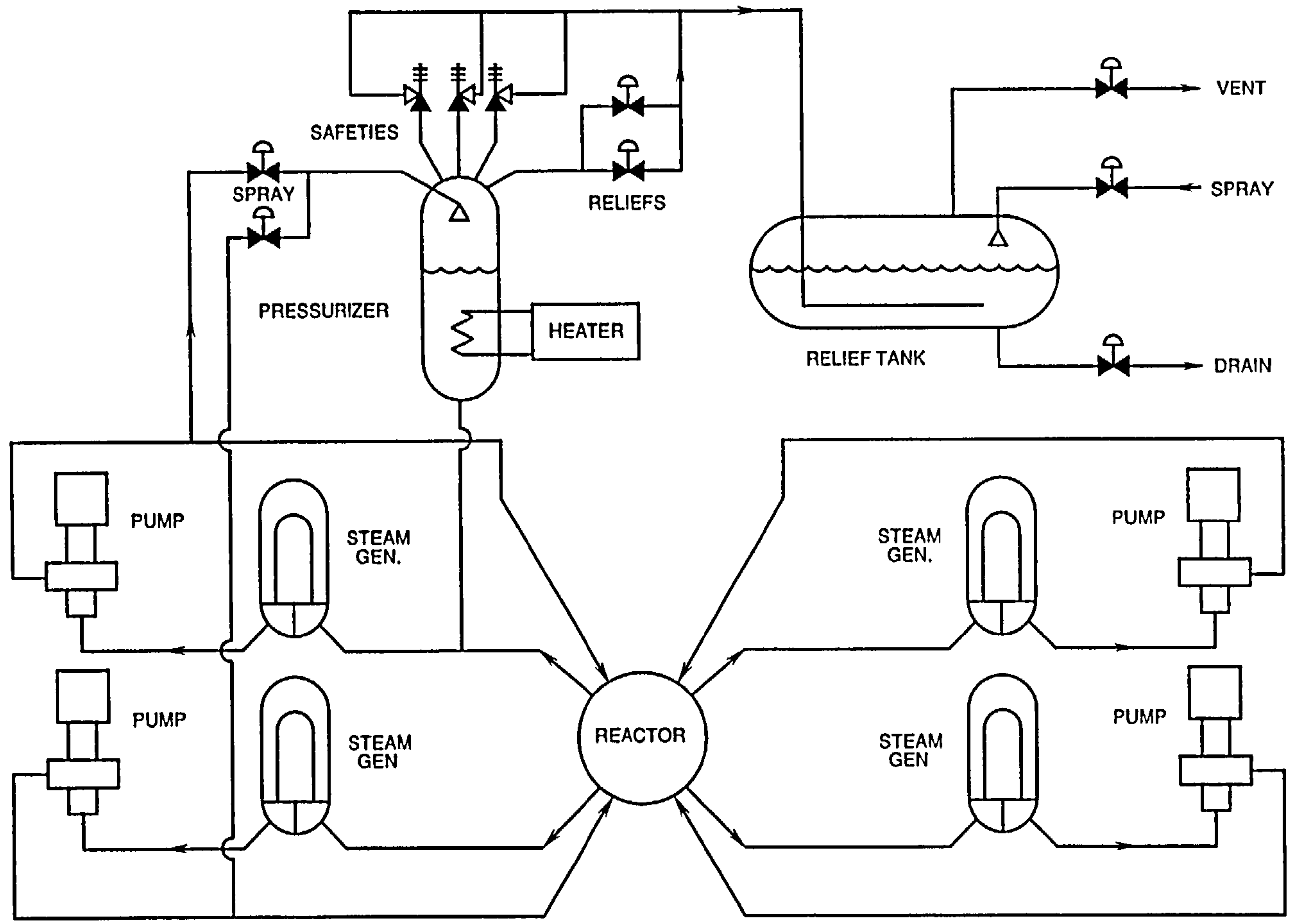


Figure 3.2-1 Reactor Coolant System



REACTOR COOLANT SYSTEM

Figure 3.2-2 Reactor Coolant System

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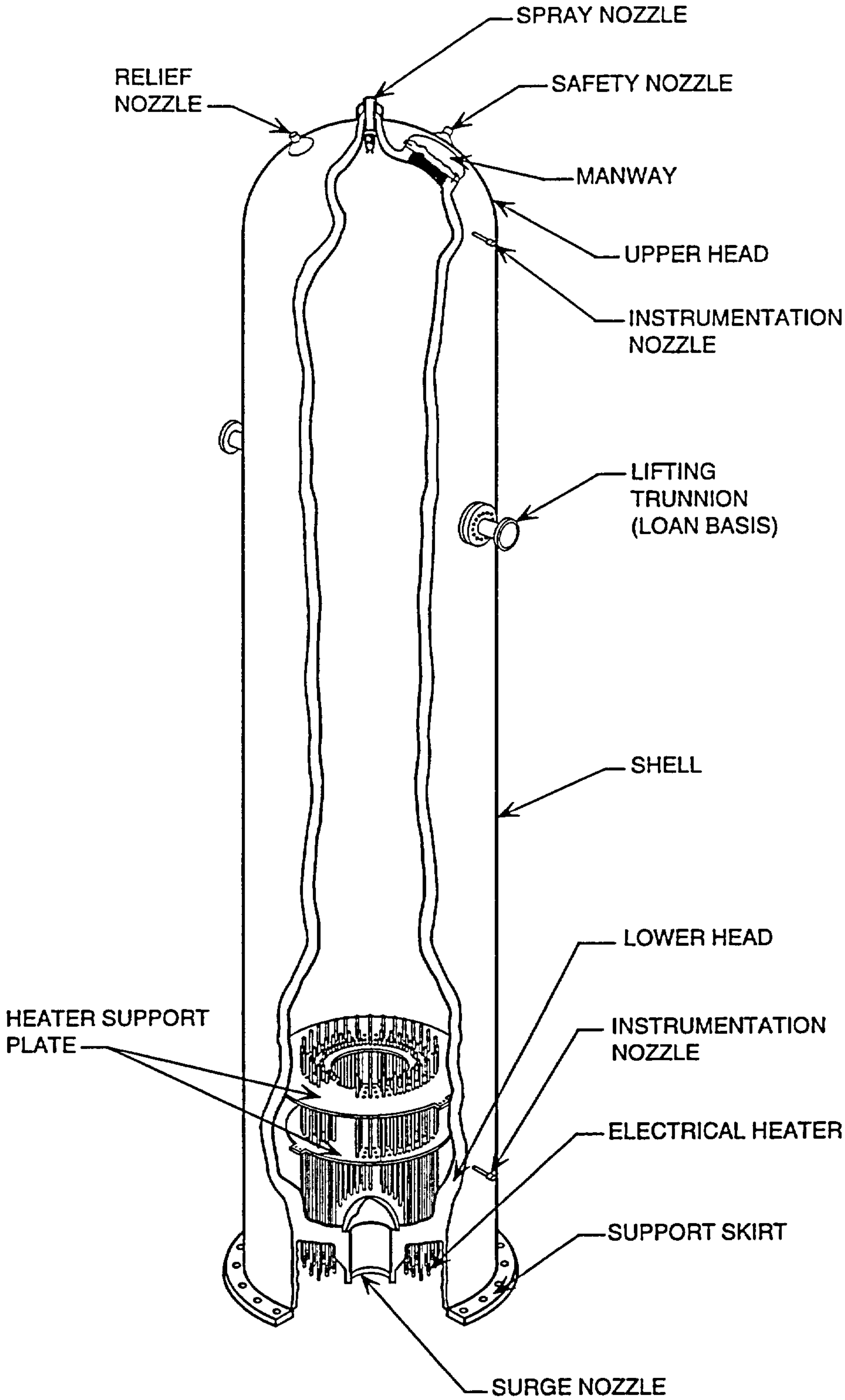

Figure 3.2-3 Pressurizer

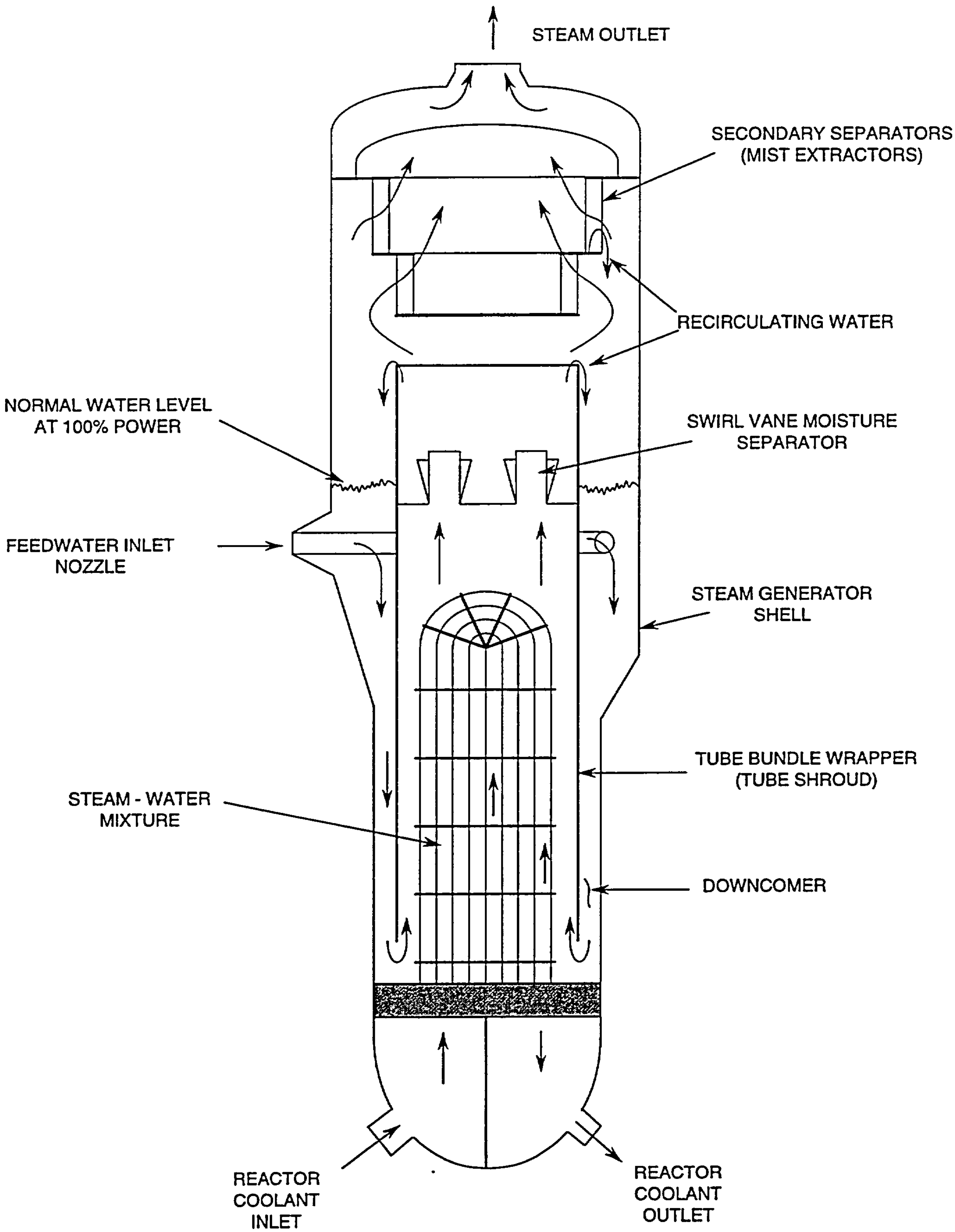

Figure 3.2-4 Steam Generator Flow Paths

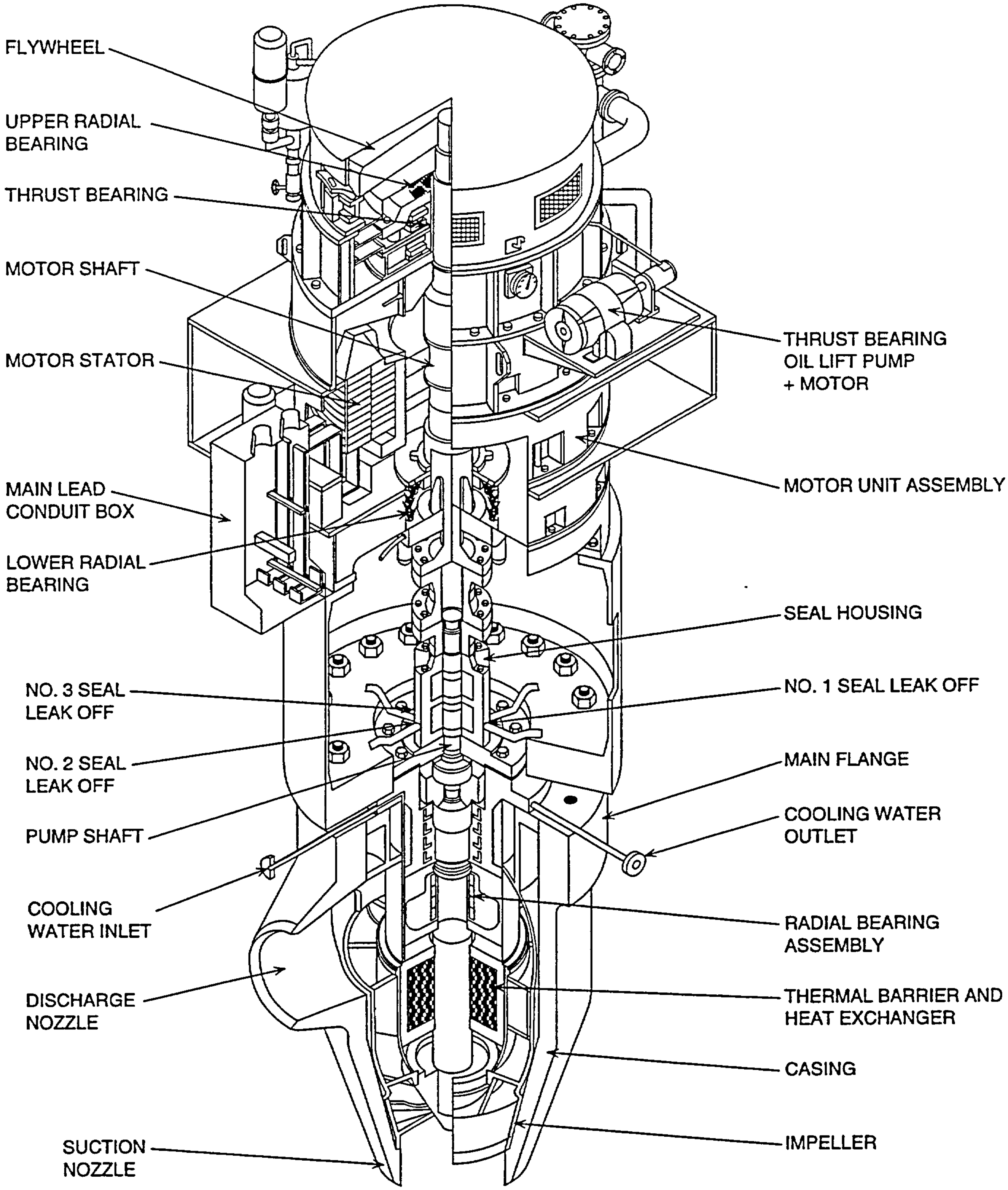

Figure 3.2-5 Reactor Coolant Pump

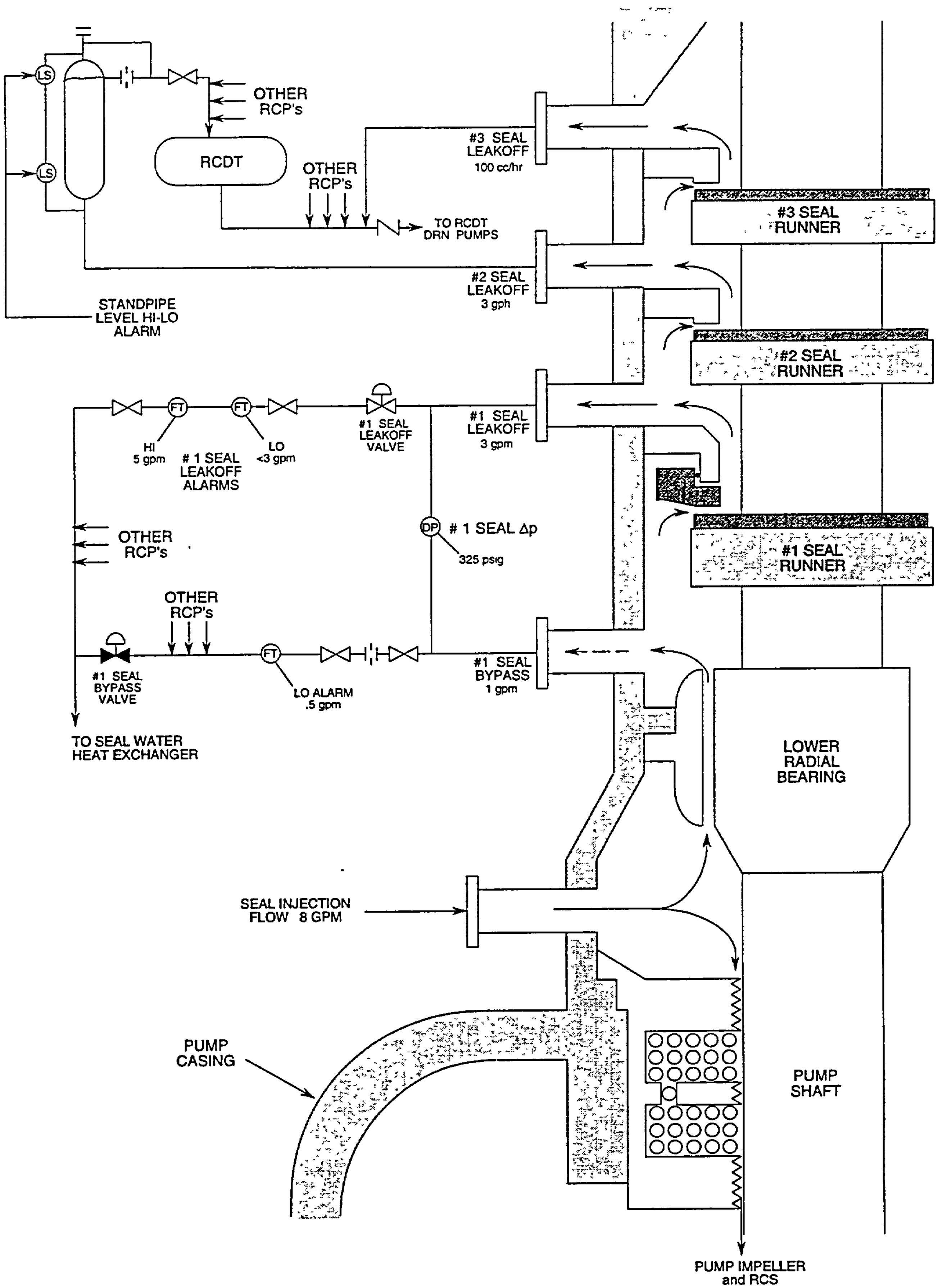

Figure 3.2-6 Reactor Coolant Pump Seal

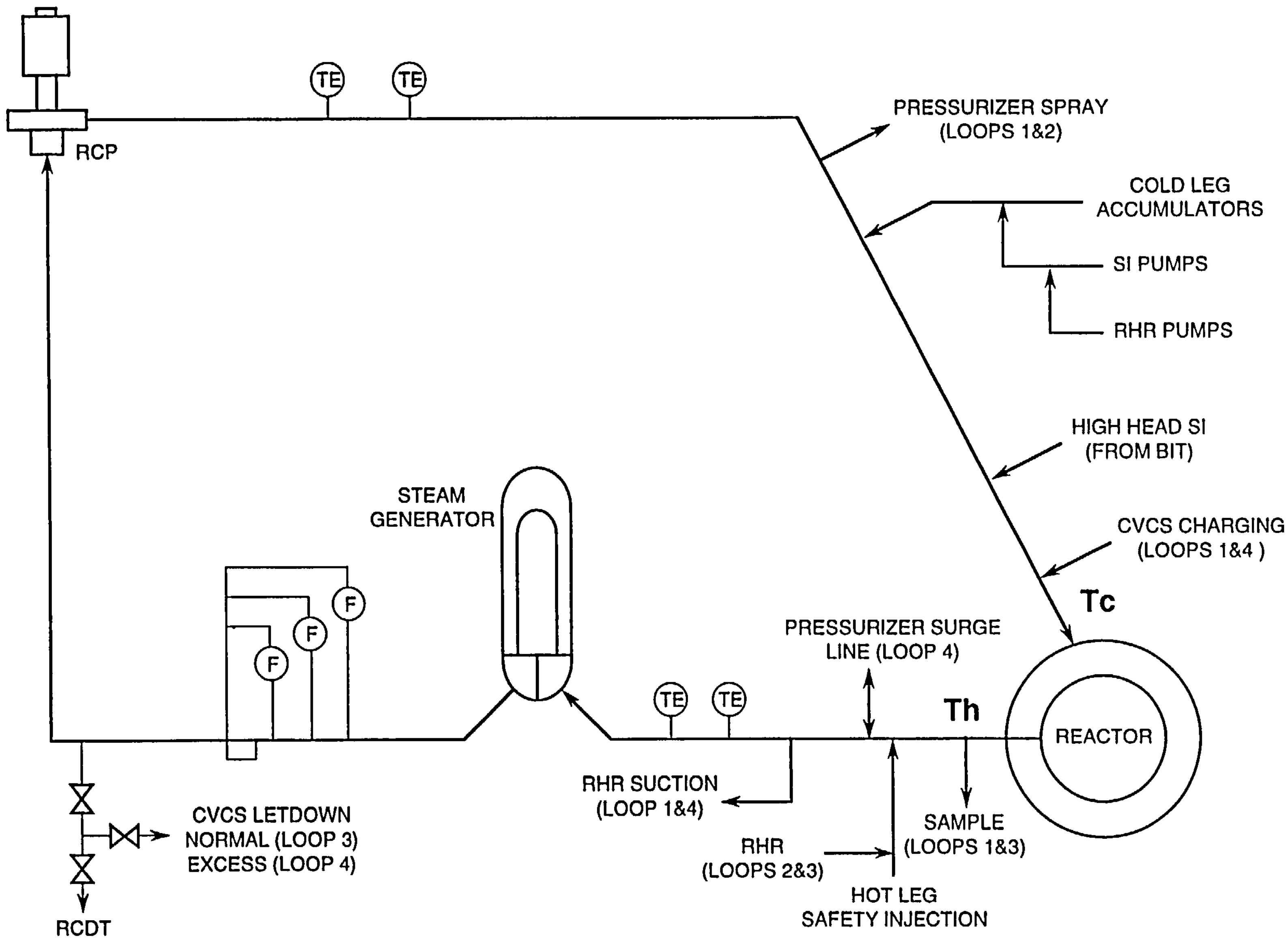

Figure 3.2-7 Reactor Coolant Loop Penetrations

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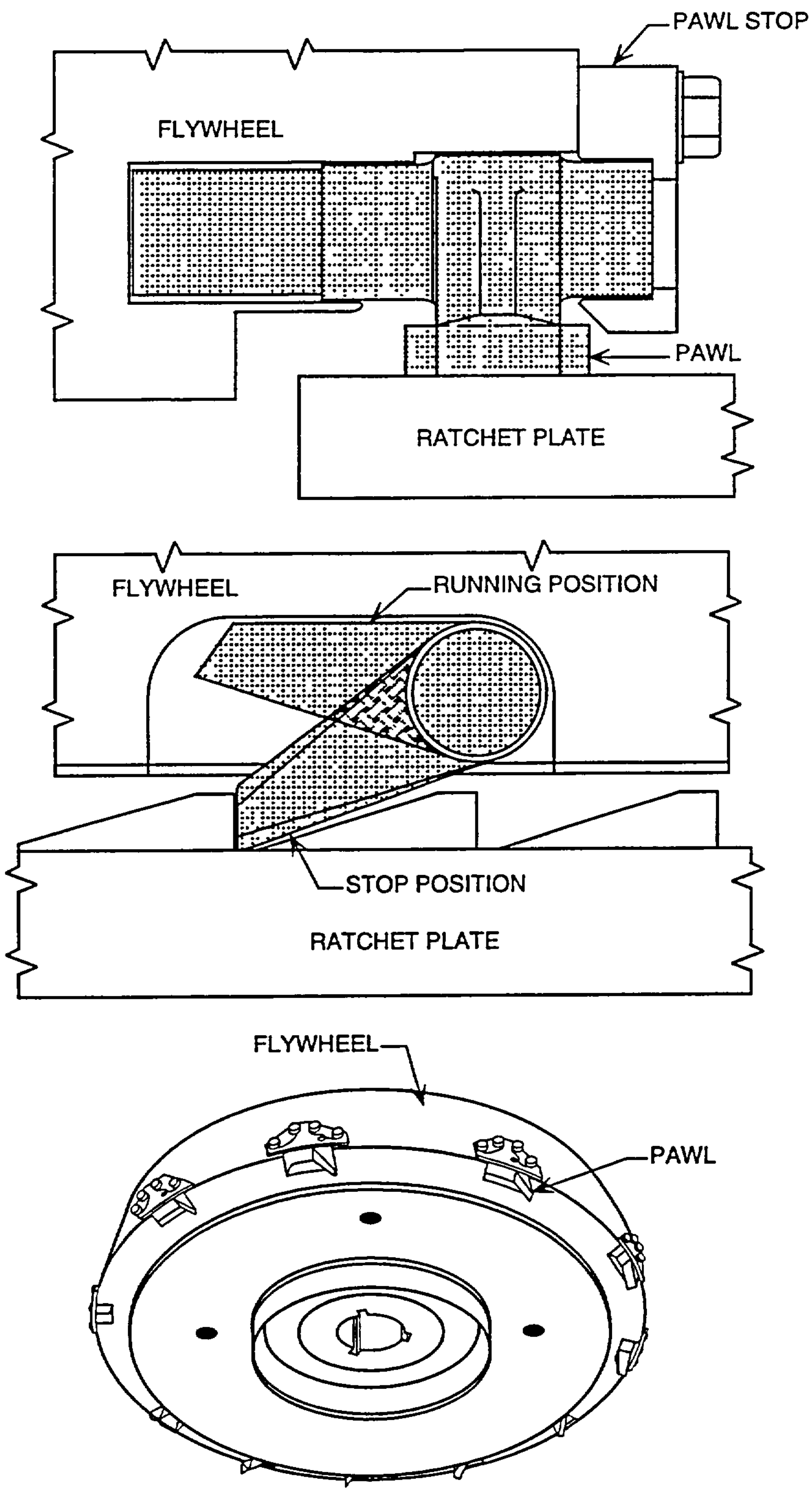

Figure 3.2-8 Reactor Coolant Pump Flywheel and Anti-reverse Rotation Device

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Chapter 4.0

Chemical and Volume Control System

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4.0 CHEMICAL AND VOLUME CONTROL SYSTEM (CVCS)

Learning Objectives:

1. List the purposes of the chemical and volume control system (CVCS).

2. List in flow path order and state the purpose of the following major components of the CVCS:

   a. Regenerative heat exchanger,
   b. Letdown orifice,
   c. Letdown heat exchanger,
   d. Ion exchangers,
   e. Letdown filter,
   f. Volume control tank (VCT), and
   g. Charging pump.

3. Identify the components in the CVCS that are used to purify the reactor coolant.

4. List in flow path order the makeup system components used to either borate, dilute, or makeup a blended flow of boric acid to the RCS.

5. Explain why the following chemicals are added to the reactor coolant system (RCS):

   a. Lithium hydroxide,
   b. Hydrogen,
   c. Hydrazine, and
   d. Boric acid.

6. List the components in the emergency boration flow path and identify one plant condition which would require its use.

7. State the purpose of the interconnection between the residual heat removal (RHR) system and the CVCS letdown.

8. State the purpose of the CVCS interface with the boron recycle system and list two plant operations that result in large amounts of influent into the system.

9. Identify the changes in the CVCS flow path that occur upon the receipt of an engineered safety features actuation signal (ESFAS).

10. State the reasons for supplying seal injection to the reactor coolant pumps (RCPs).

4.1 Introduction

The purposes of the CVCS are to:

1. Purify the reactor coolant to maintain the reactor coolant activity within design limits,

2. Adjust RCS boron concentration,

3. Maintain the desired coolant inventory in the RCS (pressurizer level control),

4. Interface with the boron recycle system, which processes reactor coolant effluent for recovery and reuse,

5. Provide a means of adding corrosion inhibiting chemicals to the RCS,

6. Provide the required seal water flow to the reactor coolant pumps,

7. Provide high head injection as part of the emergency core cooling systems, and

8. Provide a means of emergency borating the RCS.

4.2 Functional Description

The purification function of the CVCS is accomplished by ion exchangers that require a very low (≈ 120°F) inlet temperature. Therefore, it is necessary to reduce the 540°F reactor coolant that is letdown from the RCS to a value that is compatible with demineralizer operation. As will be discussed later, the temperature reduction is accomplished in two steps. After purification, the letdown is collected in a tank and pumped back into the RCS.

As shown in Figure 4-1, the letdown section of the CVCS starts at one of the four intermediate legs of the RCS and travels to the regenerative heat exchanger, which provides the initial temperature reduction of the letdown stream. Since the regenerative heat exchanger is cooled by the returning charging stream, the charging is preheated, thus minimizing the thermal shock to the RCS. The thermal shock comes from charging cold water into hot reactor coolant system piping. In addition, a little efficiency is gained by preheating the charging.

From the outlet of the regenerative heat exchanger, the letdown stream is routed through a letdown orifice, which is installed to regulate the quantity of letdown flow (normally 75 gallons per minute). The regenerative heat exchanger and letdown orifices are located in the containment building.

The letdown is piped from the letdown orifice to the letdown heat exchanger, which is used to provide the final temperature reduction of the letdown fluid. The letdown heat exchanger transfer its heat to the component cooling water system.

After the temperature of the water has been reduced by the letdown heat exchanger, it is routed to the purification components. The first purification device is the ion exchanger, which chemically removes soluble impurities by ion exchange. The second purification device is the letdown filter.

The letdown filter prevents the entry of ion exchanger resin into the chemical and volume control system and provides mechanical filtration of the letdown.

The next major component in the CVCS is the volume control tank (VCT). It functions as the collecting point for the letdown and aids the pressurizer in the control of RCS volume. The charging pump takes a suction on the VCT, increases the pressure of the fluid, and returns it to the RCS via the regenerative heat exchanger.

4.3 Detailed Description

Reactor coolant enters the CVCS via two redundant letdown isolation valves that are interlocked closed by a low pressurizer level signal. The purpose of this interlock is to prevent the letdown system from lowering pressurizer level below a prescribed low limit during those transients involving an outsurge from the pressurizer.

From the outlet of the isolation valves, the coolant flows to the regenerative heat exchanger. In the heat exchanger, letdown temperature is reduced from approximately 540°F to approximately 290°F. Heat removal is accomplished by routing the charging flow through the heat exchanger. As previously stated, preheating the charging prior to its entry into the reactor coolant system minimizes thermal stresses on the charging penetration.

Three letdown orifices and associated orifice isolation valves are located downstream of the regenerative heat exchanger. The orifice(s) are used to determine the quantity of letdown. Two of the orifices are designed to pass 75 gpm. One of these orifices is rated at 45 gpm and is used to increase letdown flow to its design maximum of 120 gpm. Additional letdown flow may be required for reactor coolant system purification or to achieve a faster change in reactor coolant system boron concentration. The letdown orifice isolation valves are used to select which orifice(s) are in service. In addition, the letdown orifice isolation valves are also interlocked closed to isolate the letdown line upon the receipt of a low pressurizer level signal.

The letdown stream is routed from the orifices and their associated outlet valves through a containment penetration with redundant letdown line containment isolation valves. Since the chemical and volume control system is not necessary to mitigate the consequences of any accident, the letdown containment isolation valves are closed by an engineered safety features signal to isolate the letdown portion of CVCS from the reactor coolant system when an accident situation is detected by the protection system.

A tap from the residual heat removal system allows the purification components of the chemical and volume control system to be used by the residual heat removal system during cold shutdown operations.

The next major component in the letdown line is the letdown heat exchanger. This heat exchanger is used to reduce the temperature of the letdown from ≈ 290°F to ≈ 120°F. The heat exchanger is cooled by component cooling water.

In order to prevent the letdown water from flashing to steam upstream of the letdown heat exchanger, pressure must be maintained on the system until the fluid temperature is reduced. The required pressure is maintained by the letdown pressure regulating valve. The letdown pressure regulator is automatically controlled by a pressure transmitter located downstream of the letdown heat exchanger.

From the outlet of the pressure regulating valve, the letdown passes through the temperature divert valve. The temperature divert valve is a three-way valve. In the normal position, the temperature divert valve directs letdown flow to the ion exchangers. In the "bypass" position, letdown flow is diverted around the ion exchangers. The position of the temperature divert valve is determined by letdown heat exchanger outlet temperature. The temperature divert valve directs flow to the ion exchangers as long as temperature is less than 140°F. When letdown heat exchanger temperature reaches 140°F, the temperature divert valve will automatically bypass letdown flow around the ion exchangers. The ion exchangers are automatically bypassed, because the ion exchanger efficiency is reduced and resin bed lifetime is shortened by high temperature.

Two mixed bed ion exchangers are installed to purify the reactor coolant system letdown. The ion exchangers are called mixed bed because both anion (removes negatively charged ions) and cation (removes positively charged ions) resins are contained in the same vessel. During normal operations, one mixed bed ion exchanger will be in service with the other bed in standby. Since each cubic foot of resin contains millions of beads, the ion exchangers are also very effective CRUD filters.

A letdown filter is located at the outlet of the ion exchangers to provide mechanical filtration and to prevent the entry of broken resin beads into the chemical and volume control system.

From the letdown filter, the water passes through the level divert valve. The level divert valve is interlocked with VCT level. If the VCT level increases to a predetermined setpoint, the level divert valve will open to divert letdown flow to the radioactive liquid waste system (holdup tanks). The VCT has a capacity of ≈ 3000 gallons. Normal water level in the VCT is ≈ 30%.

The VCT collects letdown flow, assists the pressurizer with RCS volume changes, provides an interface with the reactor makeup control system, and provides a means of hydrogen addition to the RCS.

If pressurizer level is above setpoint, the charging flow will be reduced. Reduced charging flow and a constant letdown will restore pressurizer level to normal. The reduction in charging flow results in an increased volume control tank level. If pressurizer level is below setpoint, charging flow will be increased. Increased charging flow and a constant letdown will raise pressurizer level to its setpoint. The water required to raise pressurizer level to its setpoint. The water required to raise pressurizer level comes from the VCT.

A hydrogen overpressure of 17 to 75 psig is maintained in the VCT. Letdown enters the volume control tank through a spray nozzle and absorbs hydrogen gas. When this fluid reaches the core, radiation causes the association of the hydrogen with any free oxygen.

Two series motor operated valves are located in the volume control tank outlet line. These valves provide redundant isolation of the charging pump suction path from the volume control tank on low-low volume control tank level or an engineered safety features actuation signal. When these valves are closed, an alternate source of water to the pumps will be supplied by the refueling water storage tank.

A chemical addition tank taps into the line from the VCT outlet to the charging pump suction. This tank allows the addition of lithium hydroxide or hydrazine to the reactor coolant system. Lithium hydroxide minimizes corrosion by maintaining the proper pH in the RCS. Hydrazine is added to the reactor coolant system during cold shutdown to scavenge oxygen.

A second tap into the piping between the VCT and the charging pump suction is the emergency boration supply. This supply consists of a motor operated valve that routes highly concentrated boric acid from the boric acid tank through the boric acid pump discharge to the charging pump suction. This path is used if a large quantity of boric acid has to be rapidly added to the RCS. Events that would require emergency boration are shutdown margin related. Some examples are trips with a rod or rods stuck out of the core, inadequate boron concentrations during shutdown or refueling conditions, or an anticipated transient without a scram (ATWS).

Two parallel motor operated valves supply the charging pump suction header with borated water from the refueling water storage tank. The valves are normally closed and will open to supply a suction to the charging pumps on a low-low volume control tank level or an engineered safety features actuation signal.

Three charging pumps are supplied to inject coolant into the reactor coolant system. Two of the pumps are of the single speed, horizontal, centrifugal type powered from vital (Class 1E) AC power, and the third is a positive displacement (reciprocating) pump equipped with variable speed drive. The positive displacement pump is powered from a non-vital AC electrical source.

Charging flow rate is determined from a pressurizer level error signal. The means of flow control for the reciprocating pump is by variation of pump speed. When operating a centrifugal charging pump, the flow path remains the same, however, charging flow control is accomplished by a modulating valve on the discharge side of the centrifugal pumps.

The centrifugal charging pumps also serve as high head safety injection pumps in the emergency core cooling system.

The discharge of the charging pumps is directed to two paths, the charging header and the seal injection header. The normal charging path passes through a manually operated valve that determines how determines the flow division between the charging header and the seal injection header, through redundant charging line isolation valves that close if an engineered safety features actuation signal is received, through the regenerative heat exchanger, and finally into the reactor coolant system. An auxiliary spray connection is available to lower pressurizer pressure in the event reactor coolant pumps cannot provide normal spray capability.

The seal injection header connects to the CVCS at the discharge of the charging pumps and directs flow to the seal injection filter. The seal injection filter is installed to collect particulate matter that could be harmful to the reactor coolant pump seal faces. The filtered seal injection water is piped to each reactor coolant pump through individual injection lines. The individual seal injection lines contain a manual throttle valve used to balance pump seal injection flow.

The final components on Figure 4-2 are concerned with seal return from the reactor coolant pumps. Seal return flow of approximately three gallons per minute exits each reactor coolant pump. The flows are combined, passed through the containment penetration, a seal water heat exchanger, and to the suction of the charging pumps. A flow balance for the chemical and volume control system is shown in Figure 4-3.

4.4 Reactor Coolant Pump Seals

To minimize the leakage of radioactive water from the reactor coolant system to the containment building via the shaft of the reactor coolant pumps, each reactor coolant pump is equipped with a seal package (Figure 4-4). The sealing of the shaft is accomplished by the #1 seal, which is a non-contact seal. The #1 seal is backed up by the #2 and #3 seals, which are contact type mechanical seals.

In order to understand the operation of the pump seal, several other components must be added to the discussion. First, a lower radial bearing is located below the #1 seal. This bearing is water lubricated and provides alignment of the pump shaft. Next, a thermal barrier and a heat exchanger provide restricted flow of cooled water to the lower radial bearing and seal in the event that seal injection is not available to the pump. The heat exchanger is cooled by the component cooling water system. During normal operation, both seal injection and component cooling water are supplied to each pump.

Approximately 8 gpm of seal injection flow is supplied to each pump from the chemical and volume control system. The seal injection flow enters the pump in an area below the lower radial bearing, and the flow is divided into two paths. About 5 gpm flows downward past the thermal barrier and heat exchanger and into the reactor coolant system, with the remaining 3 gpm flowing up past the lower radial bearing and into the seal package. The 3 gpm flow past the lower radial bearing and #1 seal provide cooling and lubrication for these components. The 3 gpm flow passes through the floating (non-contact) #1 seal, where hydrostatic forces maintain a fixed gap between the seal ring and seal runner. Piping connected to the pump above the #1 seal returns the majority of the 3 gpm flow back to the charging pump suction via the seal water heat exchanger. A small amount of flow passes through the #2 and #3 seal for cooling. Leakage past the #2 and #3 seals is collected and routed to the reactor coolant drain tank.

Component cooling water to the pump is not required if seal injection is available. Of particular interest is the flow of water through the pump in the event seal injection is lost. Should this occur, reactor coolant system water will flow up through the thermal barrier heat exchanger, which will reduce its temperature. From the thermal barrier, the cool water will lubricate the lower radial bearing and pass through the seal package as described above. This feature allows continued pump operation as long as component cooling water is available to the heat exchanger.

In summary, the pump may be operated if <u>either</u> component cooling or seal injection are available. However, if both are lost, the pump must be shutdown.

4.5 Reactor Makeup System

The reactor makeup system (Figure 4-5) must be able to:

a. Decrease reactor coolant system boron concentration to add positive reactivity,

b. Increase reactor coolant system boron concentration to add negative reactivity, and

c. Compensate for reactor coolant system leakage while maintaining a constant boron concentration.

To decrease reactor coolant system boron concentration, pure water is added (dilution). The source of this water is the primary water storage tank, which has a capacity of approximately 200,000 gallons. From the primary water storage tank, the water is pumped by the primary makeup water pump through a valve that controls the flowrate (FCV), through the blender, and through an isolation valve into the volume control tank via the inlet nozzle. If a large quantity of water is added, volume control tank level will increase until the level divert valve directs letdown flow to the holdup tanks.

An increase in boron concentration requires the addition of concentrated boric acid to the reactor coolant system (boration). Concentrated boric acid (≈ 20,000 ppm) is stored in the boric acid tank, which has a capacity of 11,000 gallons. Since 20,000 ppm represents a super saturated solution at room temperatures, electric heaters are installed to maintain the boric acid in solution. Boron concentration of 21,000 ppm is a 12 weight percent solution. Some plants use 7 weight percent (12,390 ppm) or 4 weight percent (7,080 ppm) to reduce problems with boron solidification. The boric acid transfer pump pumps boric acid from the boric acid tank, through the boric acid flow control valve, through the blender, through the boric acid isolation valve, and finally into the charging pump suction.

A few facts concerning the boric acid flow path are listed below:

1. The piping in the boric acid flow path is heat traced with electrical heaters to ensure that the boric acid remains in solution.

2. Highly concentrated boric acid is not normally added through the volume control tank spray nozzle because the boric acid flow could crystallize and plug the flow nozzle.

3. Since the blender restricts boric acid flow, the emergency borate flowpath is used in emergency situations.

Finally, both boric acid and pure water are added to compensate for normal reactor coolant system leakage. Additions made for this reason do not involve a change in reactor coolant system boron concentration. Boric acid and pure water are mixed int he blender with the outlet concentration being determined by the relative flowrates of the pure water and boric acid. The blended flow is adjusted by the operator to match the boric acid concentration in the reactor coolant system. From the blender, the solution enters the charging pump suction header via the boric acid isolation valve and into the reactor coolant system.

4.6 Engineered Safety Features

Several changes occur in the chemical and volume control system when an engineered safety features actuation signal is received. These changes are listed below:

1. Letdown is isolated by closing the letdown containment isolation valves.

2. The normal charging path is isolated by closing the redundant charging line isolation valves.

3. The suction to the charging pump is transferred from the volume control tank to the refueling water storage tank by closing the series volume control tank outlet valves and opening the parallel refueling water storage supply valves.

4. Both <u>centrifugal</u> charging pumps are started.

5. The centrifugal charging (high head safety injection) pumps discharge through isolation valves which open upon an engineered safety features actuation signal.

4.7 Boron Recycle System

The boron recycle system (Figure 4-5) is provided to allow reclaiming of the liquid effluents from various reactor plant systems. By recycling these effluents, the amount of water processed by the liquid waste processing system can be reduced, minimizing the release to the environs. Effluents to be recycled are first directed to one of three holdup tanks. Most of the liquid in the holdup tanks will come from the divert valve in the chemical and volume control system letdown line. This water is discharged from the reactor coolant system during startup, shutdown, load changes, and from boron dilution to compensate for fuel burnup. Other inputs include the spent fuel pit, reactor coolant drain tank, and the boron injection tank.

The contents of one tank are normally being processed by the boric acid evaporator while another tank is being filled. The third tank is available for water storage as required.

The total storage capacity of the three holdup tanks is equal to four reactor coolant system volumes. The tanks are constructed of stainless steel and are provided with a cover gas to prevent the introduction of oxygen to the tank contents. A recirculation pump is provided to mix the contents of a tank for sampling or for transferring the contents from one tank to another.

The liquid in the holdup tank to be processed is transferred by one of the boric acid evaporator feed pumps to the boric acid evaporator - gas stripper package. Before entering the evaporator, the liquid is passed through the evaporator feed ion exchangers to remove unwanted ions (primarily cesium and lithium).

Two boric acid evaporator - gas stripper packages are provided. Each package will process approximately 30 gpm of dilute radioactive boric acid solution and produce pure distillate and a concentrate of boric acid stripped of radioactive gases. Radioactive gas stripping is designed to reduce the influent gas concentration by a factor of 10^5. The gases stripped are vented to the gaseous waste disposal system vent header. After gas stripping, the liquid is passed to the evaporator section.

Condensate produced by the evaporator is sent through the evaporator condensate demineralizers to the monitor tanks. The evaporator condensate demineralizers are hydroxyl based anion beds designed to remove any borate ions contained in the condensate.

In the monitor tanks, the liquid is sampled, and a determination is made as to its final disposition.

Possible paths from the monitor tanks are:

1. Primary water storage tank - normal,
2. Lake discharge tank - to be released to the environment,
3. Holdup tanks - for reprocessing, or
4. Evaporator condensate demineralizer - for reprocessing.

When the concentrates produced by the evaporator reach 12 weight percent boric acid, they are transferred to the concentrates holding tank for sampling. If it is at the proper concentration and contains no chemical impurities, it is sent to the boric acid tanks for reuse.

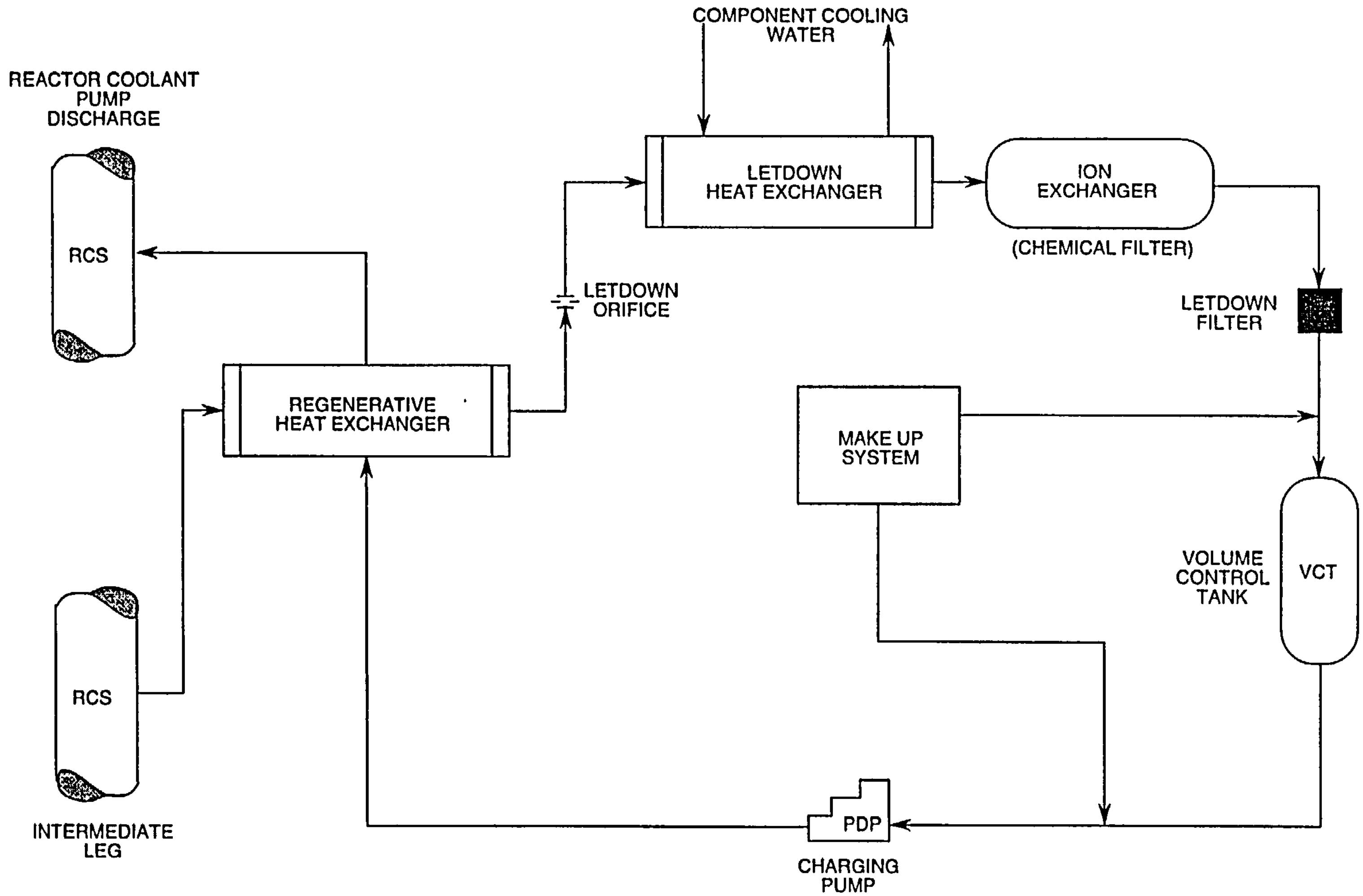

Figure 4-1 CVCS Functional Diagram

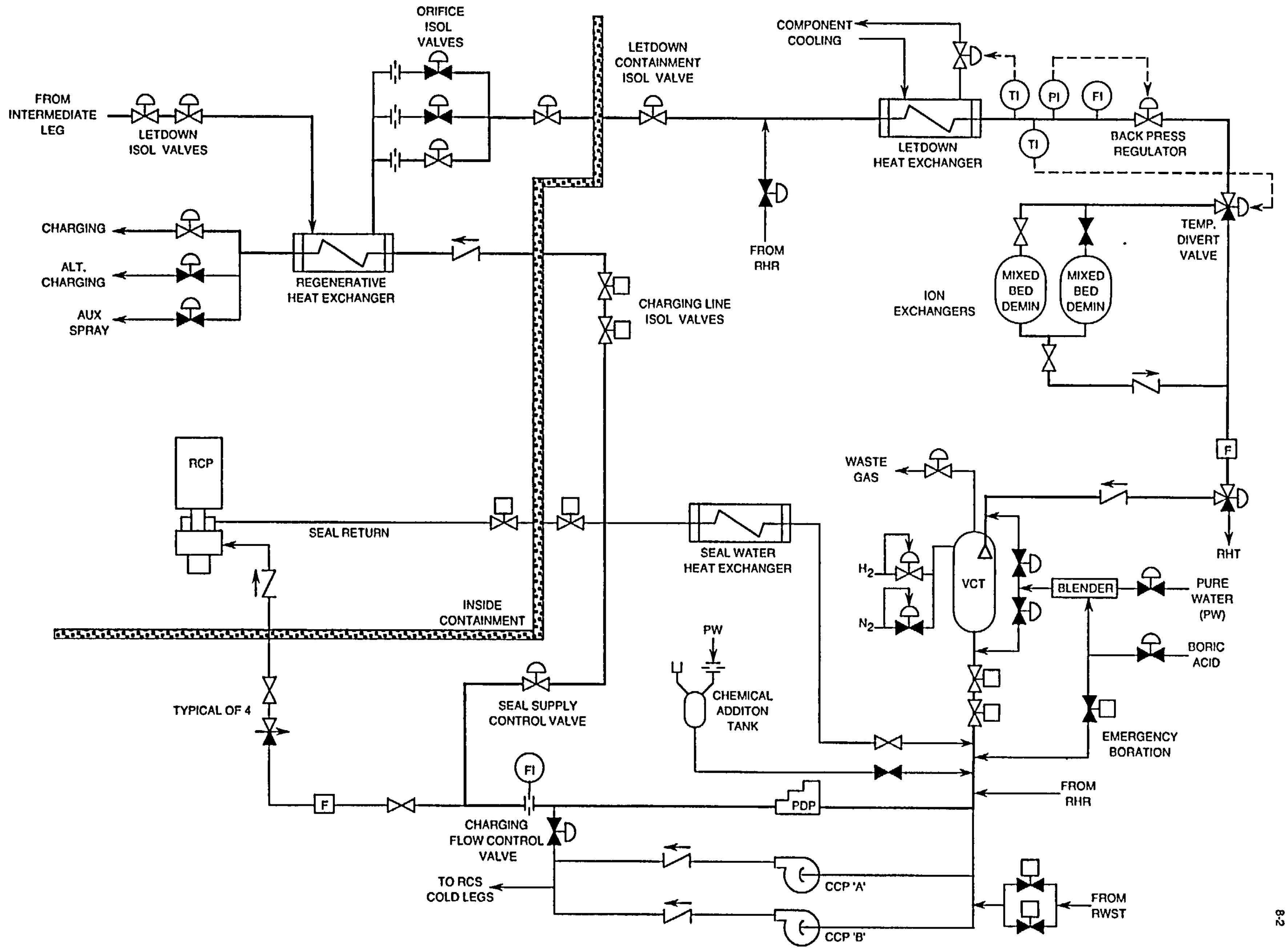

Figure 4-2 Chemical and Volume Control System

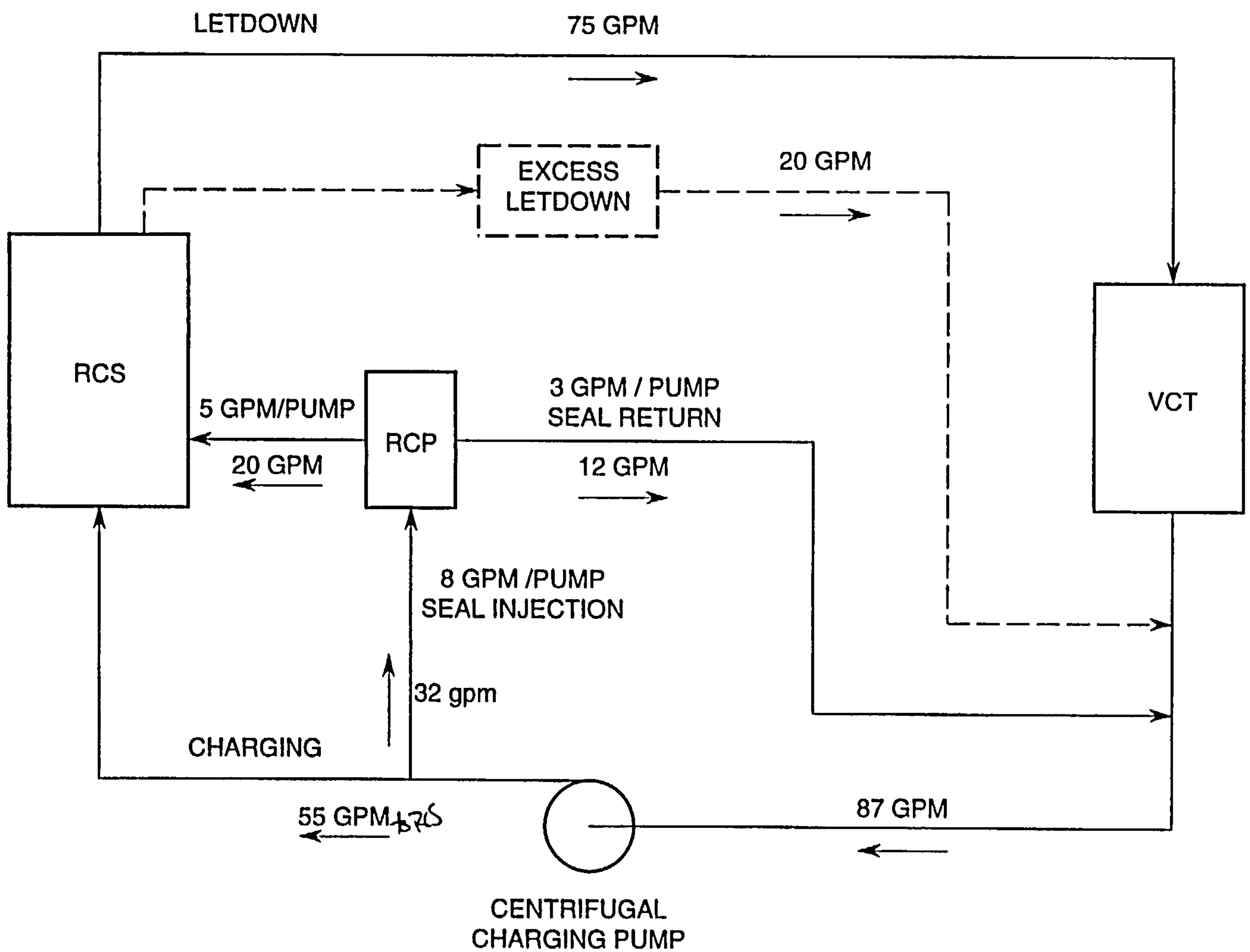

Figure 4-3 CVCS Flow Balance

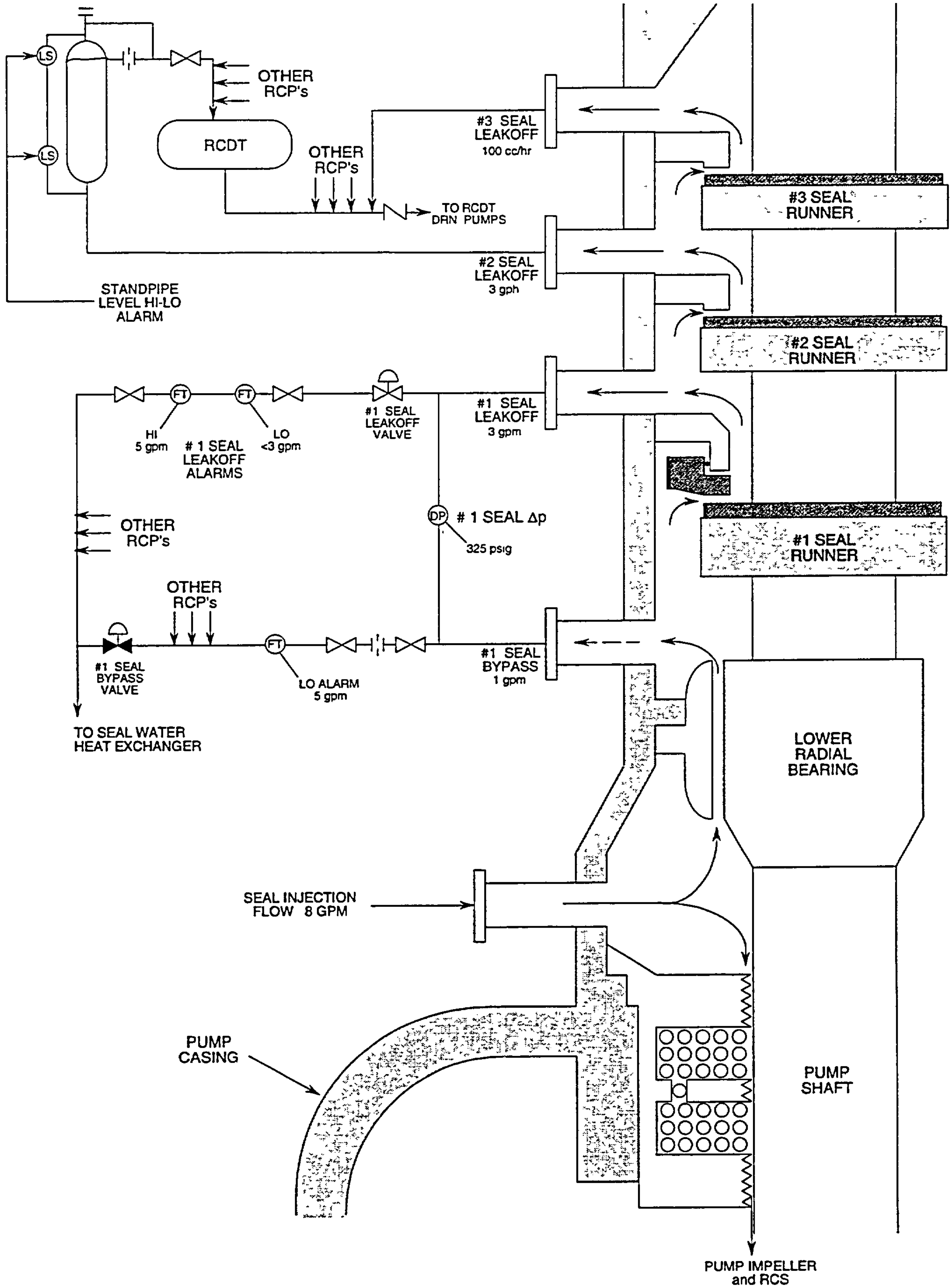

Figure 4-4 Reactor Coolant Pump Seal

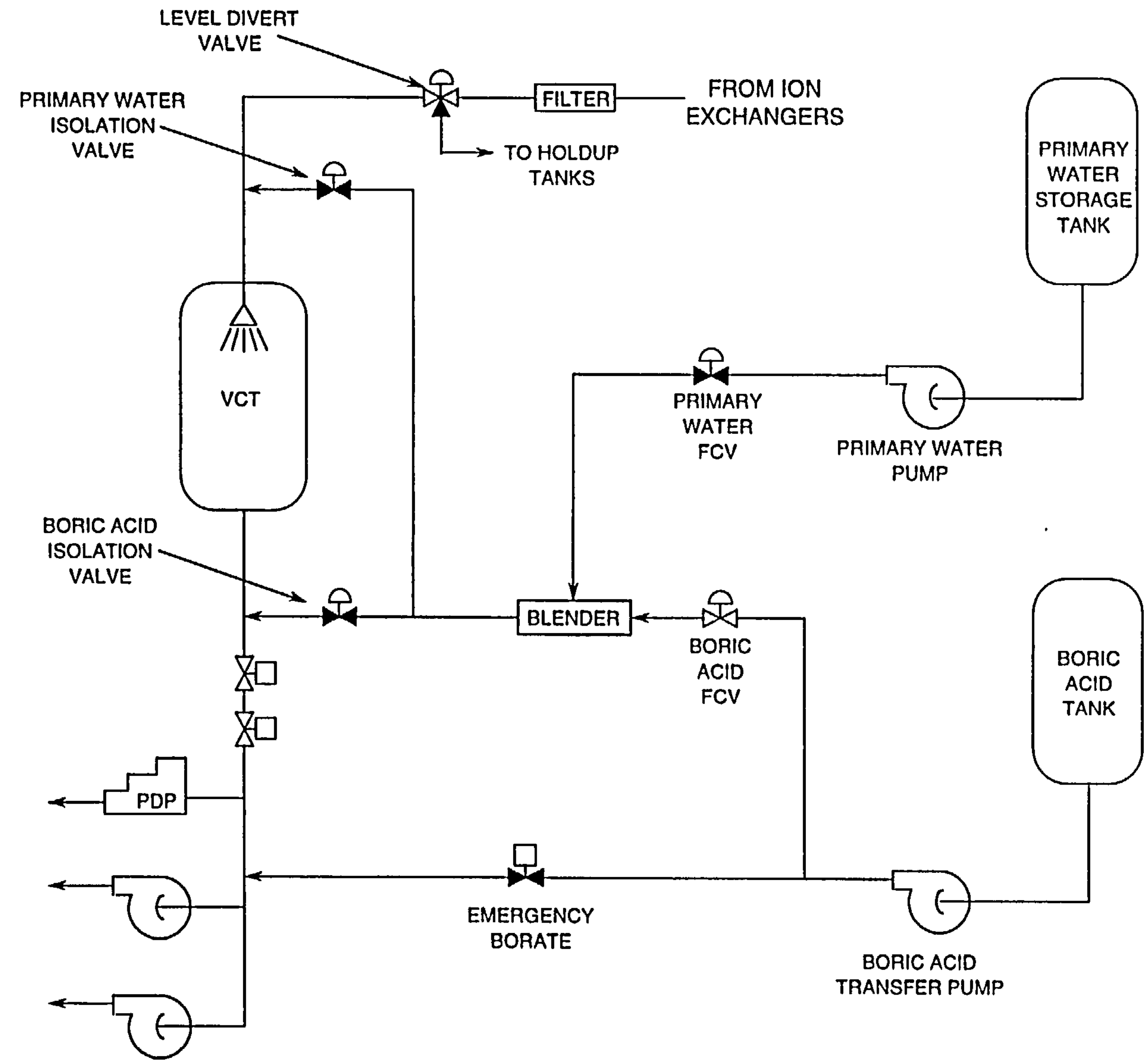

Figure 4-5 Reactor Makeup System

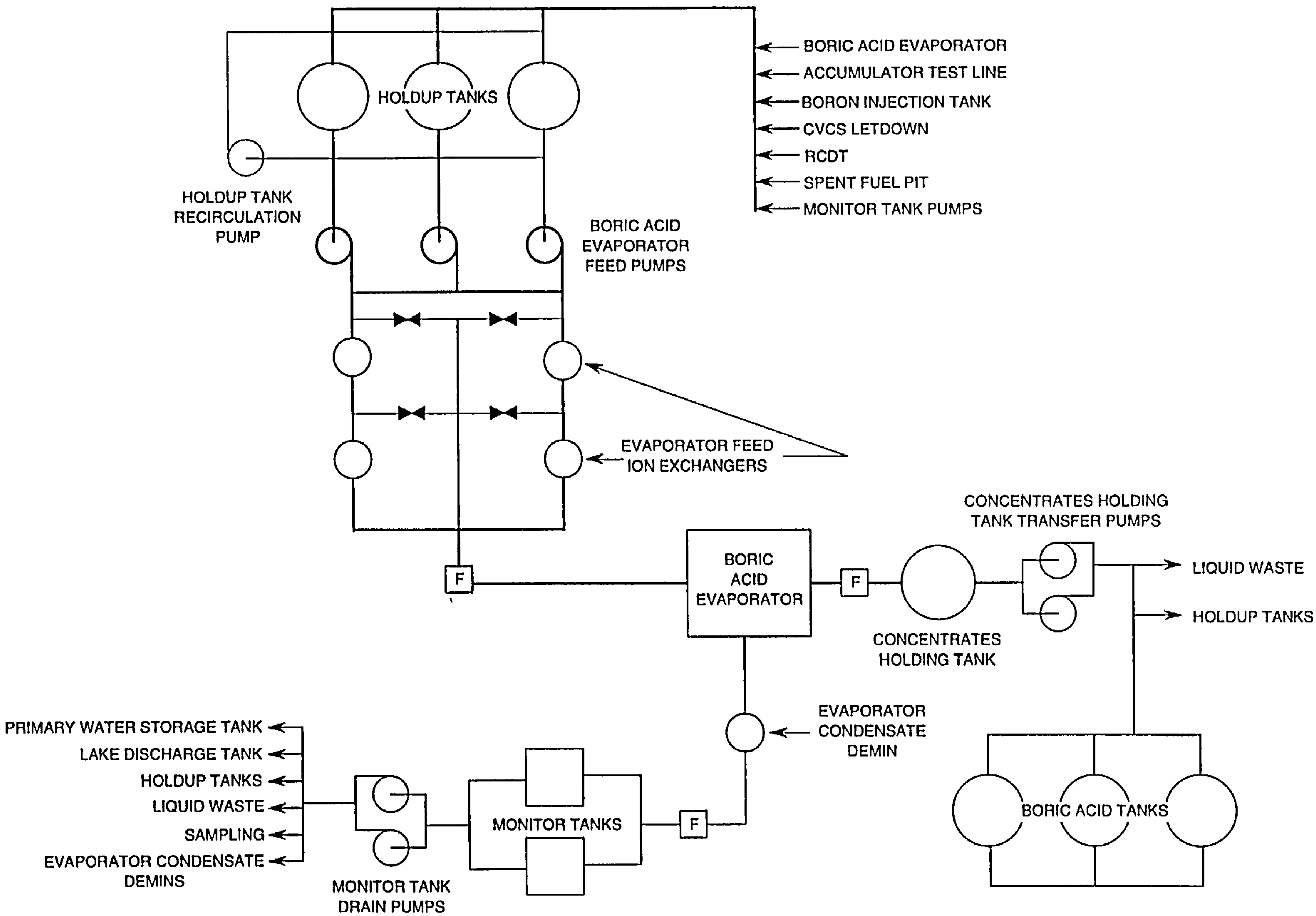

Figure 4-6 Boron Recycle System

Westinghouse Technology Manual

Section 5.1

Emergency Core Cooling Systems

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5.1 EMERGENCY CORE COOLING SYSTEMS

Learning Objectives:

1. Explain why emergency core cooling systems are incorportated into plant design.

2. Describe the operation of the emergency core cooling systems during the following conditions:

   a. Injection phase and
   b. Recirculation phase.

3. State the purposes of the residual heat removal system.

4. Describe the residual heat removal system flow path, including suction supplies, discharge points, and major components during the following operations:

   a. Decay heat removal,
   b. Injection phase, and
   c. Recirculation phase.

5. State the purposes of the following systems:

   a. Accumulator injection system,
   b. Safety injection pump system, and
   c. High head injection system.

6. State the purpose of the following components:

   a. Refueling water storage tank and
   b. Containment recirculation sump.

7. List the order of emergency core cooling systems injection during the following abnormal conditions:

   a. Inadvertent actuation (at normal operating temperature and pressure),
   b. A small (slow depressurization of the reactor coolant system) break loss of coolant accident, and
   c. A large loss of coolant accident.

8. List all engineered safety features actuation signals and the accident(s) for which each signal provides protection.

5.1.1 Introduction

The purposes of the emergency core cooling systems (ECCS) are to provide:

1. Core cooling to minimize fuel damage following a loss of coolant accident (LOCA) and
2. Additional shutdown margin following a steam line break accident.

The purposes of the residual heat removal (RHR) system (active system) are to provide:

1. Low pressure, high volume safety injection to complete the reflooding of the core following a LOCA,
2. A flow path and heat sink for long term core cooling following a LOCA, and
3. Decay heat removal during a plant cooldown below 350°F.

The purpose of the accumulators (passive system) is to rapidly reflood the core following a large LOCA.

The purpose of the safety injection pump system (active system) is to provide intermediate head, low volume safety injection for small to intermediate size LOCAs.

The purpose of the high head injection system (active system) is to provide:

1. High pressure, low volume safety injection for small to intermediate size LOCAs and
2. Charging flow for the chemical and volume control system during normal operations.

5.1.2 System Description

5.1.2.1 Emergency Core Cooling Systems

The ECCS will supply borated water to the reactor core in the event of a LOCA and maintain the reactor in a shutdown condition during the cooldown accompanying a steam line break accident.

The ECCS is composed of four subsystems (Figure 5.1-1). Three of these subsystems are connected to a single source of borated water (refueling water storage tank). These are the active systems which require mechanical and electrical realignment to inject water into the reactor coolant system (RCS). The fourth subsystem is a passive system which will inject water only if RCS pressure is sufficiently reduced. Some of these subsystems or their components are also utilized in normal plant operations.

The operation of the ECCS following a LOCA may be divided into two distinct modes or phases of operation: the injection phae and the recirculation phase. The injection phase occurs after the initial blowdown of the RCS is complete. The ECCS transfer water from the refueling water storage tank (RWST) to the RCS and reactor core. This injection will cover the core and provide cooling. In addition, any reactivity increase accompanying the accident will be nullified by the borated injection flow.

The recirculation phase starts when the RWST is empty, and the suctions of the ECCS are supplied from the containment recirculation sump via the residual heat removal (RHR) system. It is during this phase that long term core cooling will be provided.

In order to meet the single failure criterion, it is necessary that each active component have a redundant 100% backup. All valves which need to be opened for proper engineered safety features functioning are redundant and in parallel. All valves which must be closed are redundant and in series. All pumps are redundant and in parallel, and the systems are designed so that only one RHR pump, one charging pump, and one safety injection pump need to operate to provide a sufficient volume of water to cool the core.

5.1.2.2 Residual Heat Removal System

The RHR system consists of two separate headers, each containing an RHR pump, heat exchanger, instrumentation, valves, and various cross-ties with other systems (Figure 5.1-2).

The RHR system is designed to remove residual and sensible heat from the reactor core and reduce the temperature of the RCS during the second phase of plant cooldown and during refueling operations. During the first phase of plant cooldown, the reactor coolant temperature is reduced by transferring heat from the RCS to the steam and power conversion system. The RHR system is utilized as a portion of the ECCS and the containment spray system during accident conditions. The RHR pumps are powered from the engineered safety features (ESF) electrical busses.

Plant Cooldown

During plant cooldown (after the RCS has been cooled to less than 350°F and depressurized to less than 425 psig), the RHR system is aligned to the cooldown mode. Two pressure-interlocked isolation valves are opened to connect the RHR pump suction to one of the RCS hot legs. Coolant flows from the RCS to the RHR pumps, through the tube side of the RHR heat exchangers. Coolant then flows back to the RCS through four RCS cold leg penetrations. The RHR heat exchangers are cooled on the shell side by the component cooling water system (Chapter 5.4).

The cooldown rate of the RCS is controlled by regulating the reactor coolant flow through the tube side of the RHR heat exchangers. Since a constant flow is required through the RHR system, a remotely operated bypass valve is installed around the RHR heat exchangers. If two RHR heat exchangers and two RHR pumps are placed in service, and each heat exchanger is supplied with component cooling water at a temperature of approximately 100°F, the RHR system will reduce the RCS temperature to 140°F within twenty hours following a reactor shutdown.

Refueling

The RHR pumps are utilized during the refueling operation to pump borated water from the refueling water storage tank to the refueling cavity. During this operation, the suction isolation valves from the RCS are closed, and the suction isolation valves from the refueling water storage tank are opened. The reactor vessel head is lifted slightly, and water from the refueling water storage tank is pumped into the reactor vessel through the normal RHR system return lines and into the refueling cavity through the open reactor vessel flange. The reactor vessel head is lifted as the water level is raised. After a sufficient water level is attained, the inlet isolation valves from the RCS opened, the refueling water storage tank supply valve closed, and normal RHR system operation is reestablished.

The RHR pumps are used to drain the refueling cavity following refueling.

RHR Operation - Injection Phase

The RHR system is the low pressure, high volume portion of the ECCS. Technical Specifications require the RHR system to be aligned for ECCS operation whenever the temperature of the RCS exceeds 350°F. The suction valve from the refueling water storage tank is open to supply 2000 ppm borated water to the suctio of the RHR pumps. All pump suction valves, heat exchanger throttle valves, and header isolation valves are fully opened and aligned so that an injection path is provided from the RHR pumps discharge into the four RCS cold legs. The two check valves in the RHR system discharge lines isolate the low pressure (600 psig) RHR system from the high pressure (2500 psig) RCS. All that is necessary for RHR injection is that the pumps start and RCS pressure drops below the maximum discharge pressure (170 psig) of the RHR pumps.

At low pressure conditions following a large LOCA, each RHR pump can deliver approximately 4500 gpm to the reactor coolant system cold legs.

RHR Operation - Recirculation Phase

When the RWST has emptied, the RHR system has the capability of taking a suction from the containment recirculation sump. The RHR heat exchangers will cool the water as it is pumped back into the RCS. Water will flow into the reactor core and out the break, providing long term core cooling. This mode of operation is designated as the recirculation phase. While operating in this mode, the RHR system may also supply the suctions of the safety injection and centrifugal charging pumps and/or the containment spray header.

The RHR system is capable of supplying water to the hot legs of the RCS. This would be done approximately 24 hours after an accident and is used to terminate any boiling in the core and to sweep out the boric acid that has accumulating in the reactor vessel.

The containment recirculation sump (Figure 5.1-3) is a stainless-steel lined sump in the lowest level of containment, where the spilled reactor coolant will collect. Wire mesh screens are installed to keep debris from entering the RHR suction piping. The RHR suction piping from the containment sump up to and including the recirculation sump isolation valve is contained in a guard pipe. This guard pipe is actually an extension of the containment boundary and is designed so that a leak in the suction piping or isolation valve will not drain the containment recirculation sump to the auxiliary building floor and negate the recirculation phase of the ECCS.

Float switches are provided in the recirculation sump to ensure adequate level for RHR pump net positive suction head (NPSH) requirements before initiating the recirculation phase of ECCS.

5.1.2.3 Accumulator System

The accumulators (Figure 5.1-4) are tanks filled with borated water (2000 ppm) and pressurized to approximately 600 psig with nitrogen gas. During normal plant operations, each accumulator is isolated from its respective RCS cold leg by two series check valves. Each accumulator motor operated isolation valve is open and power removed to prevent inadvertent closing. Should the RCS pressure decrease below accumulator pressure (as during a LOCA), nitrogen gas pressure on top of the water will force the check valves open as borated water flows into the RCS. Mechanical operation of the swing-check valve is the only action required to open the injection path from the accumulator to the reactor core. The accumulators are passive ESF because no external power source or initiation signal is needed to obtain a fast acting, high injection flow rate if the need arises.

The design capacity of the accumulators is based upon the assumption that flow from one of the accumulators spills onto the contianment floor through a ruptured loop. Flow from the remaining accumulators provides sufficient water to fill the volume outside the core barrel below the nozzles, the bottom plenum, and also cover one-half of the core.

The accumulators are located outside the missile barriers inside the containment. Each accumulator is provided with connections for remotely filling, draining, and adjusting nitrogen pressure.

5.1.2.4 Safety Injection Pump System

The safety injection (SI) system (Figure 5.1-5) is the intermediate pressure, intermediate volume portion of the ECCS. Whenever the RCS temperature is greater than 350°F, the SI system will be aligned with a suction supply from the RWST and a discharge path to all four RCS cold legs through the same penetrations used by the RHR system and accumulators. As in the RHR system, isolation from the RCS is provided by two series check valves in the discharge lines. All that is necessary for SI pump injection on a LOCA is for the pumps to start and RCS pressure to decrease below the pumps discharge pressure (approximately 1500 psig). If the break is small and RCS pressure remains high, the SI pumps will recirculate back to the RWST. Each SI pump has a rated flow of approximately 550 gpm.

When the RWST is emptied and the recirculation phase has been initiated, the SI pump system may be manually realigned to take suction from the "B" train of the RHR system. This is necessary because the SI pumps cannot take a suction directly from the containment sump because of suction elevation and water temperature (NPSH). The SI system is also capable of supplying water to the hot legs of the RCS.

5.1.2.5 High Head Safety Injection System

The centrifugal charging pumps (Figure 5.1-6) are used for the high head safety injection system. These pumps are the high pressure, low volume portion of the ECCS.

During the injection phase, the two centrifugal charging pumps are started to inject concentrated boric acid solution into the RCS cold legs through separate loop penetrations. This provides negative reactivity for small LOCAs where pressure remains high for a longer period of time. Water containing boric acid is drawn into the pumps from the RWST. The pumps are capable of injection boric acid into the RCS regardless of break size. The fluid is delivered to the reactor vessel through a common header and four branch lines into each cold leg. Throttling valves in each branch line are adjusted to equalize flow going to the RCS and to minimize the amount of injection water loss should one of these lines break.

The centrifugal charging pumps are normally aligned for chemical and volume control system operations. Upon receipt of an engineered safety features actuation signal, the pumps start and three groups of series valves close to isolate the normal charging path. Two valves in parallel at the pump inlet open to admit water from the RWST. The two groups of two normally closed parallel valves will open to align the charging pumps for injection.

When the source of water from the RWST is depleted and recirculation is initiated, the centrifugal charging pumps take a suction from the "A" train of the RHR system. Ths is necessary because the charging pumps cannot take a suction directly from the containment sump. If the "A" train of the RHR system is not available, the suction of the charging pumps may be manually aligned to the suction of the safety injection pumps.

5.1.3 Operations

5.1.3.1 Engineered Safety Features Actuation

The engineered safety features are actuated from the engineered safety features portion of the reactor protection system (Figure 5.1-7). The actuation logic consists of four automatic signals and one manual input, which in turn starts various systems and components including the isolation of non-safty systems that penetrate the containment. The following list is comprised of the input signals to the engineered safety features and what accident will initiate each signal:

1. Low pressurizer pressure - loss of coolant accident,
2. High steam flow coincident with either low-low Tavg or low steam pressure - steam line break downstream of the main steam isolation valves,
3. High steam line differential pressure (any one steam line lower than the others) - steam line break upstream of the main steam line check valves,
4. High containment pressure - loss of coolant accident, a steam line or feed line break inside contianment, and
5. Manual - operator initiated signal when deemed necessary.

When any of these signals are sensed, the logic section will turn on, and the engineered safety features will initiate a reactor trip signal (the reactor trip may already have occurred) and the following systems/components will start:

1. Diesel generators,
2. Auxiliary cooling water systems,
3. Auxiliary feedwater system, and
4. Emergency core cooling systems.

The following actions will also occur:

1. Main feedwater isolation (prevents overcooling of the RCS) and
2. Containment phase A isolation (closes all non-essential systems penetrating the containment).

To prevent inadvertent resetting or stopping of the engineered safety feature systems/components before proper analysis of plant conditions, a time delay reset circuit is incorporated in the engineered safety features logic. After the timer has cycled, the reset pushbutton may be depressed. This turns off the actuation signal but does not change the operational status of any system or component. After the reset has taken place, individual systems and components may be actuated or turned off by the operator, as plant conditions dictate.

5.1.3.2 ECCS Integrated Operation

Injection Phase

The accumulators (Figure 5.1-4) are passive components requiring no external source of power or signal to perform their intended function. The accumulators represent the principle injection mechanism because they are the first system or component to be effective for a large LOCA. The stored energy of compressed nitrongen in the accumulators inject borated water

(2000 ppm) into the cold legs of the RCS when the primary system pressure falls below 600 psig. The active components will realign (valves open or close) and all ECCS pumps start. The active components serve three functions during the injection phase:

1. Provide rapis injection of concentrated boric acid to ensure the reactor remains in a shutdown condition,

2. Complete the reflooding process for large size ruptures where the initial refill is accomplished by the accumulators. The accumulators have enough capacity to recover a minimum of one-half of the core, and

3. Provide injection for small size ruptures where the primary coolant pressure does not drop below the accumulator pressure for an extended period of time after the accident.

The high head injection system must realign to perform its function. Motor operated valves realign the suction of the centrifugal charging pumps from the volume control tank to the RWST. The centrifugal charging pumps then deliver borated water at RCS pressure to the four cold legs of the RCS. The injection points are separate from those used by the accumulators.

The safety injection pumps take a suction from the RWST and deliver borated water to the four cold legs. These pumps develop a maximum discharge pressure of about 1500 psig and deliver water to the RCS only after pressure is reduced below this value. This limitation on discharge pressure does not significantly reduce the effectiveness of the safety injection pumps since breaks of sufficient size to require safety injection will generally reduce the coolant pressure below 1500 psig.

In the injection mode, the low head RHR pumps take suction from the RWST and deliver borated water to the same four cold leg connections used by the safety injection pumps and the cold leg accumulators. The low head RHR pumps deliver water only when the RCS is depressurized below 170 psig.

All active components of the ECCS which operate during the injection phase of a LOCA are located outside the containment building. The ECCS pumps are located in the auxiliary building.

Recirculation Phase

The injection phase of the LOCA is terminated just before the RWST is emptied. Water level indication and alarms on the RWST inform the operator that sufficient water has been injected into the containment to allow initiation of recirculation with the RHR pumps and provides ample warning to terminate the injection phase while the operating pumps still have adequate suction pressure. Level indicators and alarms are provided in the recirculation sump to provide backup inidication so that the injection phase can be terminated and recirculation phase initiated.

During the recirculation phase, the RCS can either be supplied directly from the discharge of the RHR heat exchangers, or the water can be directed from each heat exchanger outlet to the suction of the charging and safety injection pumps, which can pump this water into the RCS at a higher pressure. The latter mode of operation could be used in the event of a small break LOCA where depressurization occurs slowly over a longer period of time.

Change Over from Injection Phase to Recirculation Phase

The change over from injection to recirculation is plant dependent. On older designs, this change over is accomplished by operator action. On newer design plants, the change over is accomplished automatically by the reactor protection system. The sequence for the change over from the injection phase to the recirculation phase is as follows:

1. The change over will start when the RWST has a low level alarm and the containment recirculation sump has a high level alarm. This ensures adequate suction for the RHR pumps.

2. The suction valves for the RHR pumps will close and the containment recirculation sump isolation valves will open.

3. After these valves have changed position, component cooling water must be admitted to the RHR heat exchangers. The recirculation flow path is now established with water from the containment sump being cooled with the RHR heat exchangers and pumped through the core and out the break.

5.1.4 Summary

The emergency core cooling systems are designed to provide:

1. Core cooling to minimize fuel damage following a loss of coolant accident and

2. Additional shutdown margin following a steam line break accident.

There are two distinct modes of operation of the ECCS known as the injection phase and the recirculation phase. The injection phase rapidly refills the reactor vessel and covers the core. The injection phase is complete when the RWST empties. Water that is collected in the containment recirculating sump from the RCS and RWST ensures adequate suction for the RHR pumps. The RHR system, when aligned to take a suction on the containment recirculating sump, will cool the water and return it to the core for long term cooling. This is known as the recirculation phase. During small break loss of coolant accidents, depressurization of the RCS is slow. The ECCS will only inject when pressure in the RCS drops below the design pressure of each system (Figure 5.1-8). The order of injection is as follows:

- High head injection,
- Safety injection,
- Cold leg accumulators, and
- Low head injection.

If an accident occurs, the engineered safety features actuation signal will start the ECCS. In addition to starting the ECCS, this actuation signal also generates a reactor trip (if one has not already occurred), starts the emergency diesel generators, isolated the feedwater system, starts the auxiliary feedwater system, and starts the auxiliary cooling water systems. Finally, this signal produces a containment phase A isolation which results in the closure of the majority of the isolation valves for non-safety systems that penetrate the containment.

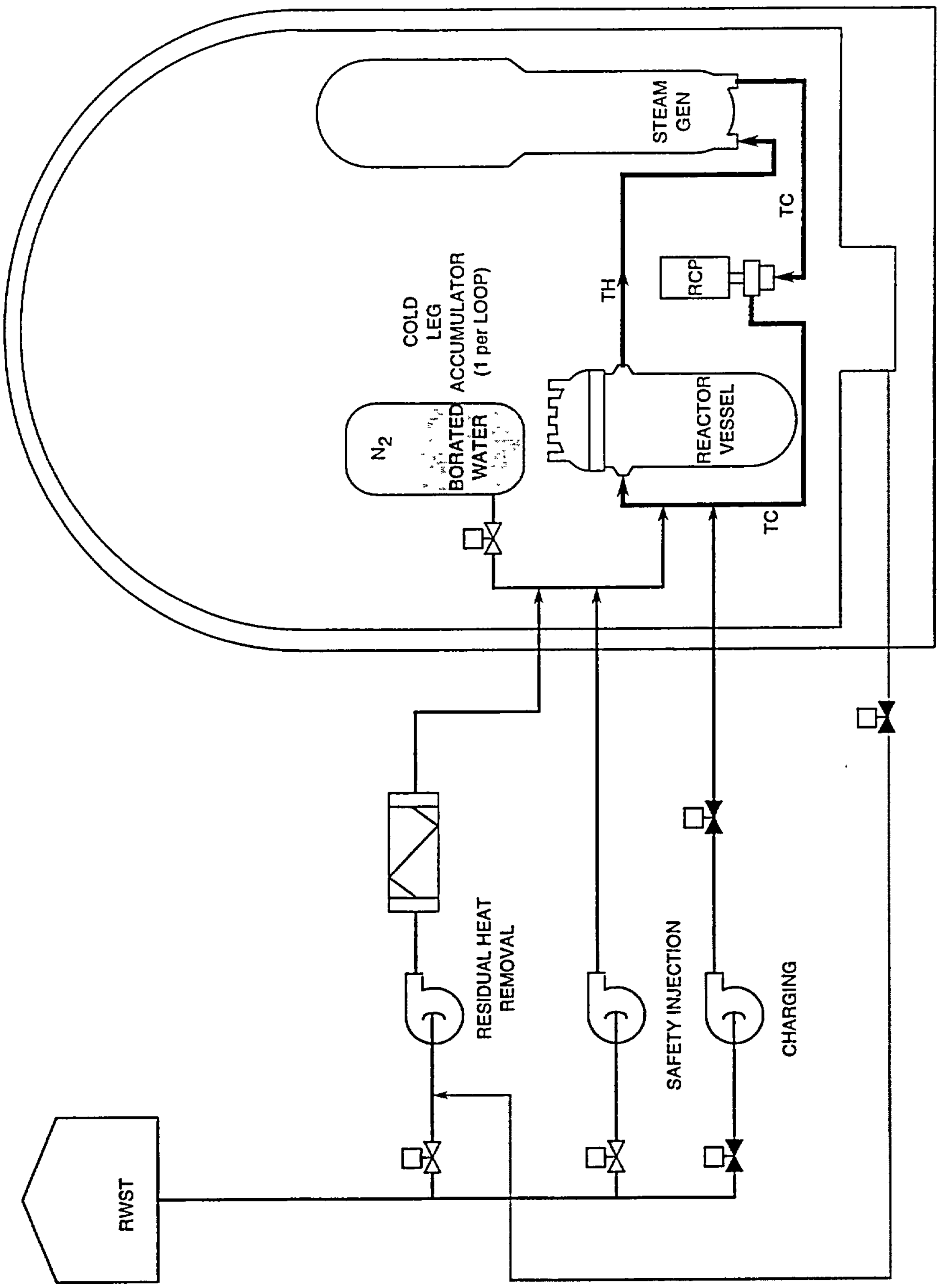

Figure 5.1-1 Emergency Core Cooling Systems (Simplified Composite)

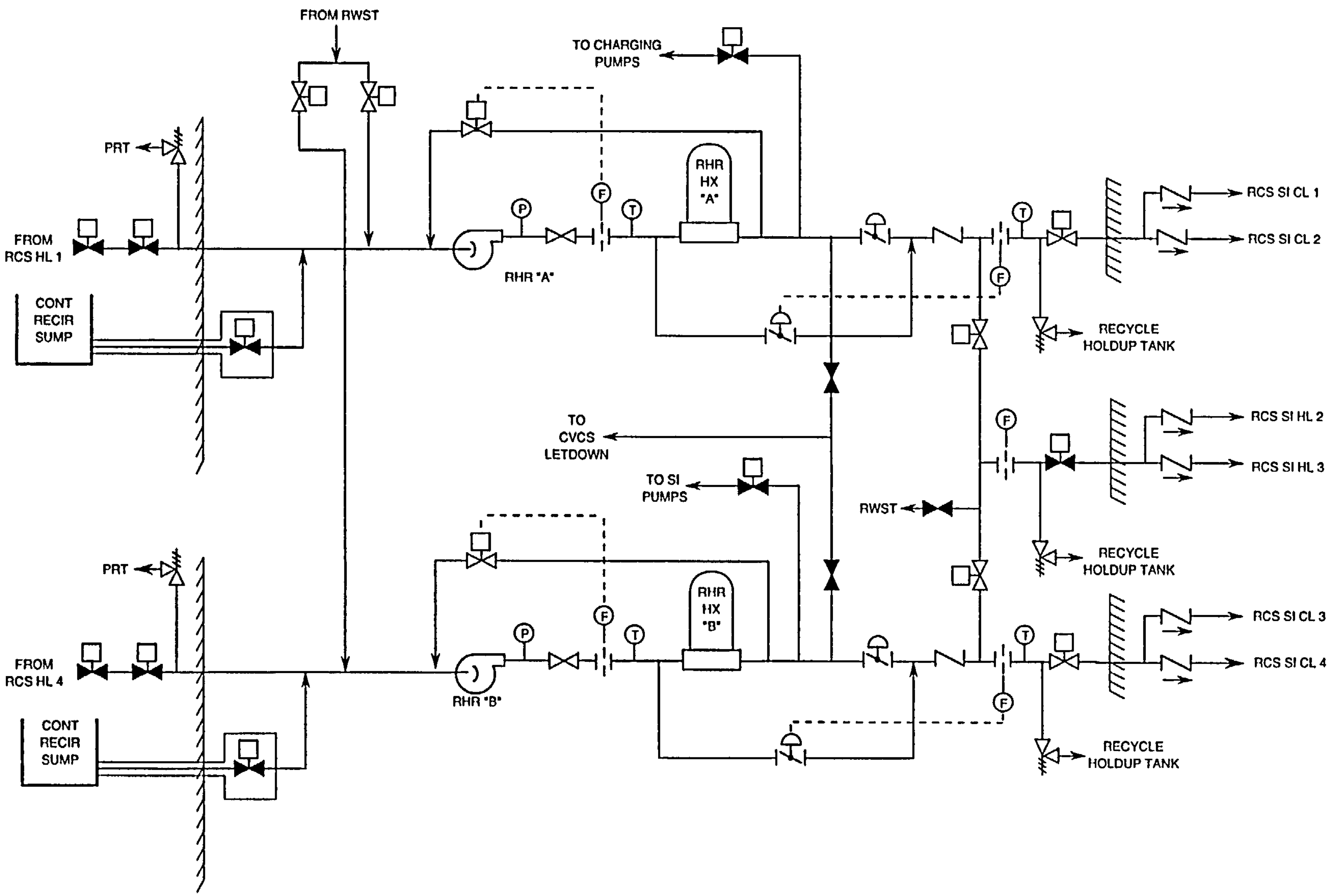

Figure 5.1-2 Residual Heat Removal System

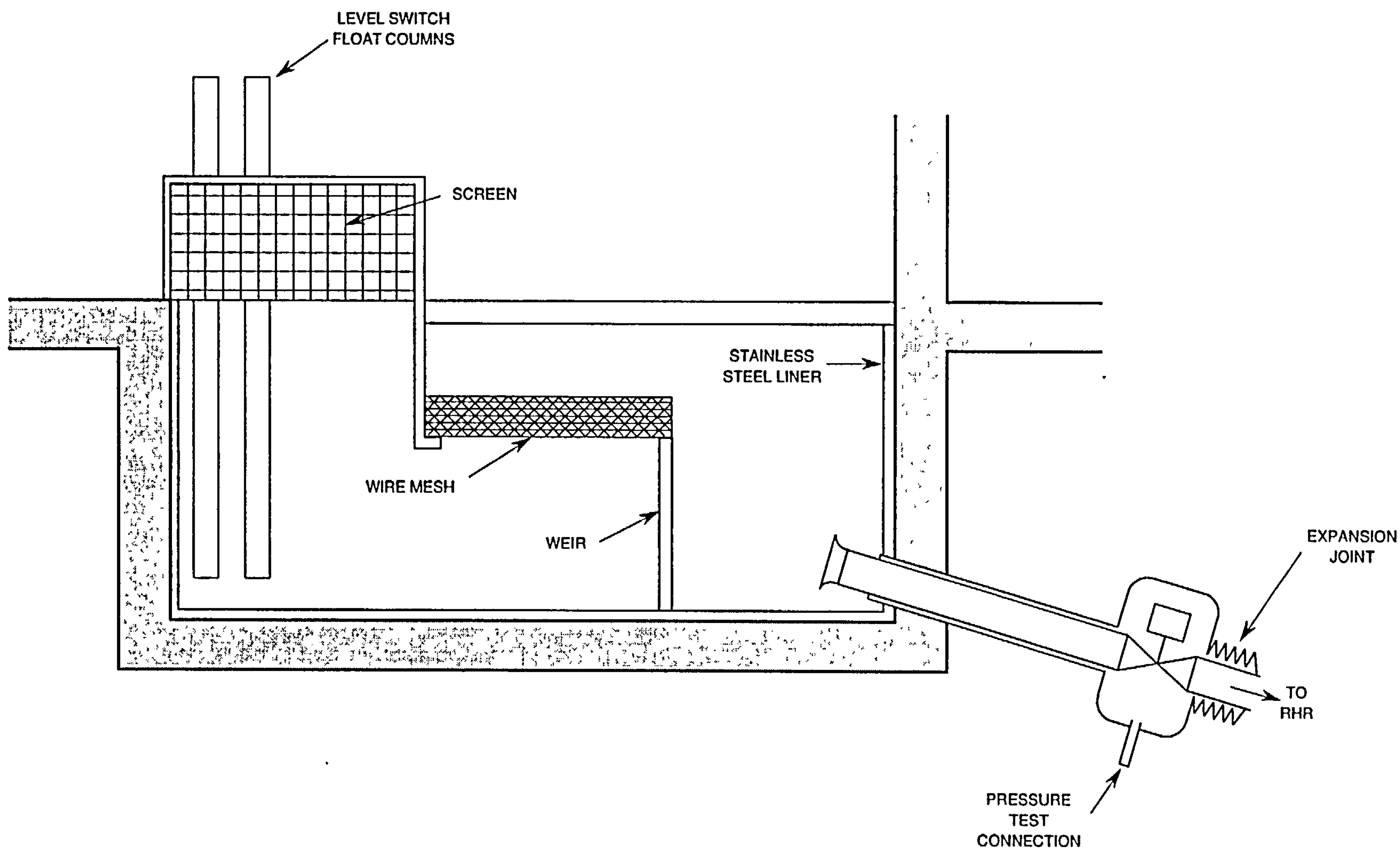

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Figure 5.1-3 Containment Recirculation Sump

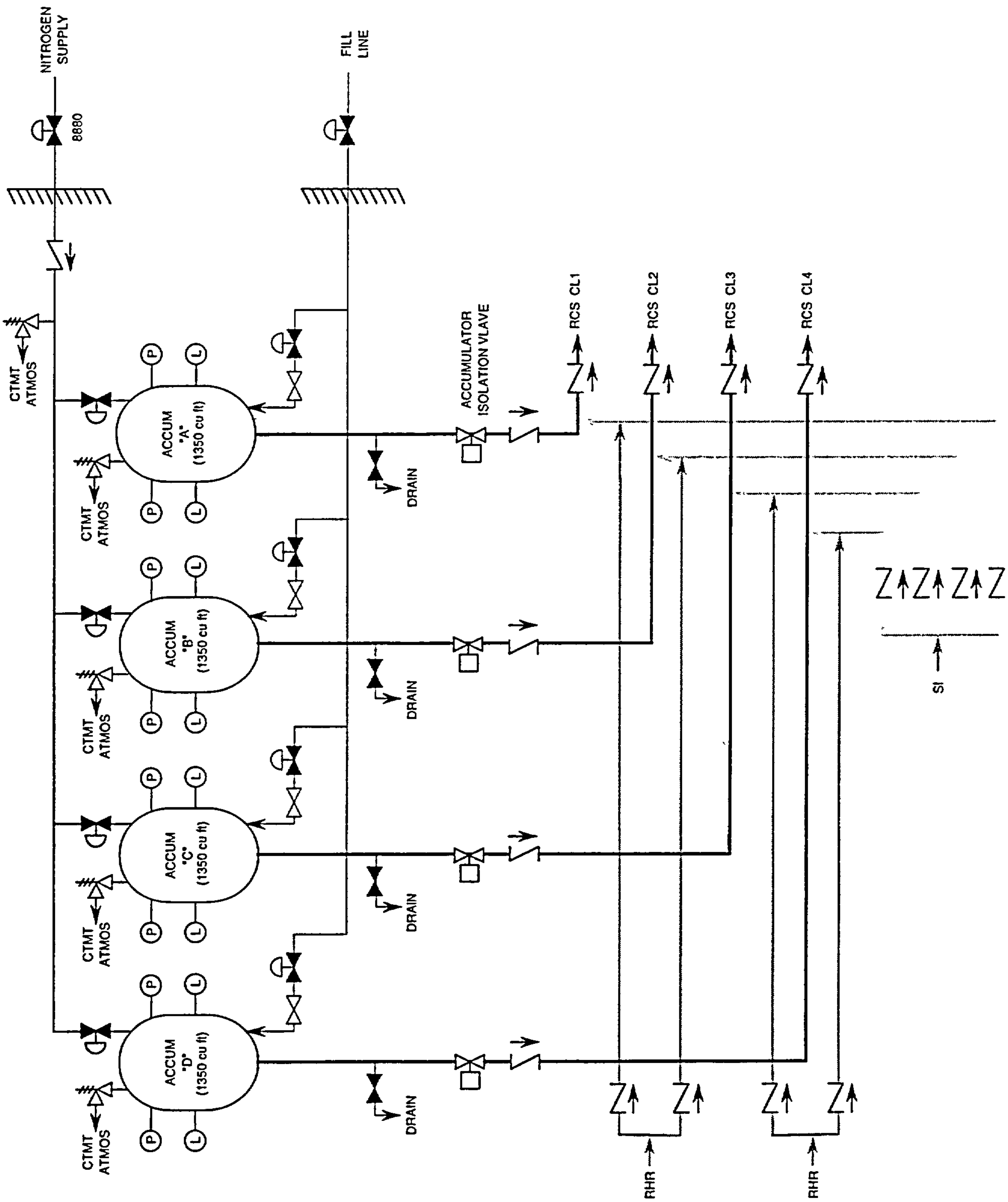

Figure 5.1-4 Cold Leg Accumulator System

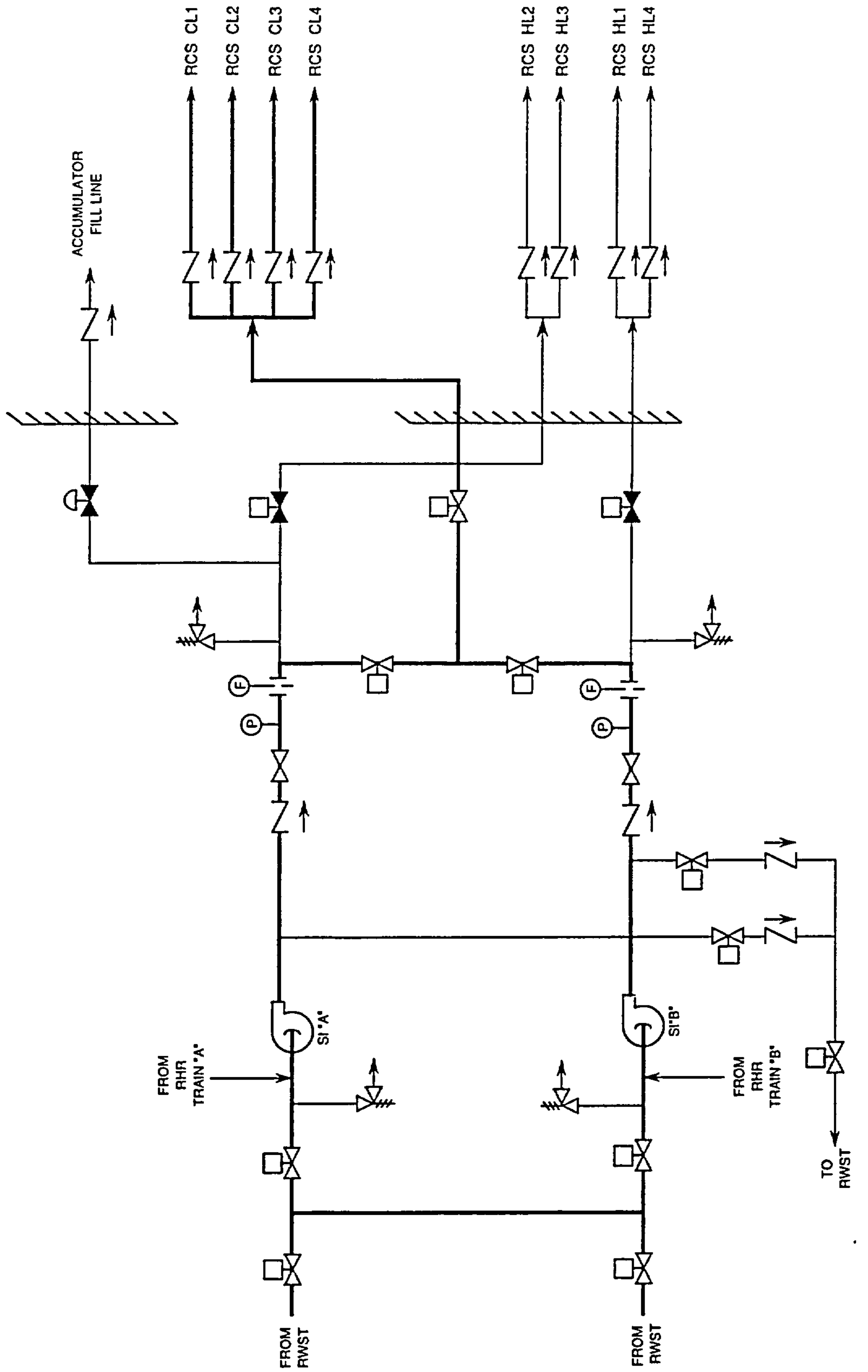

Figure 5.1-5 Safety Injection System

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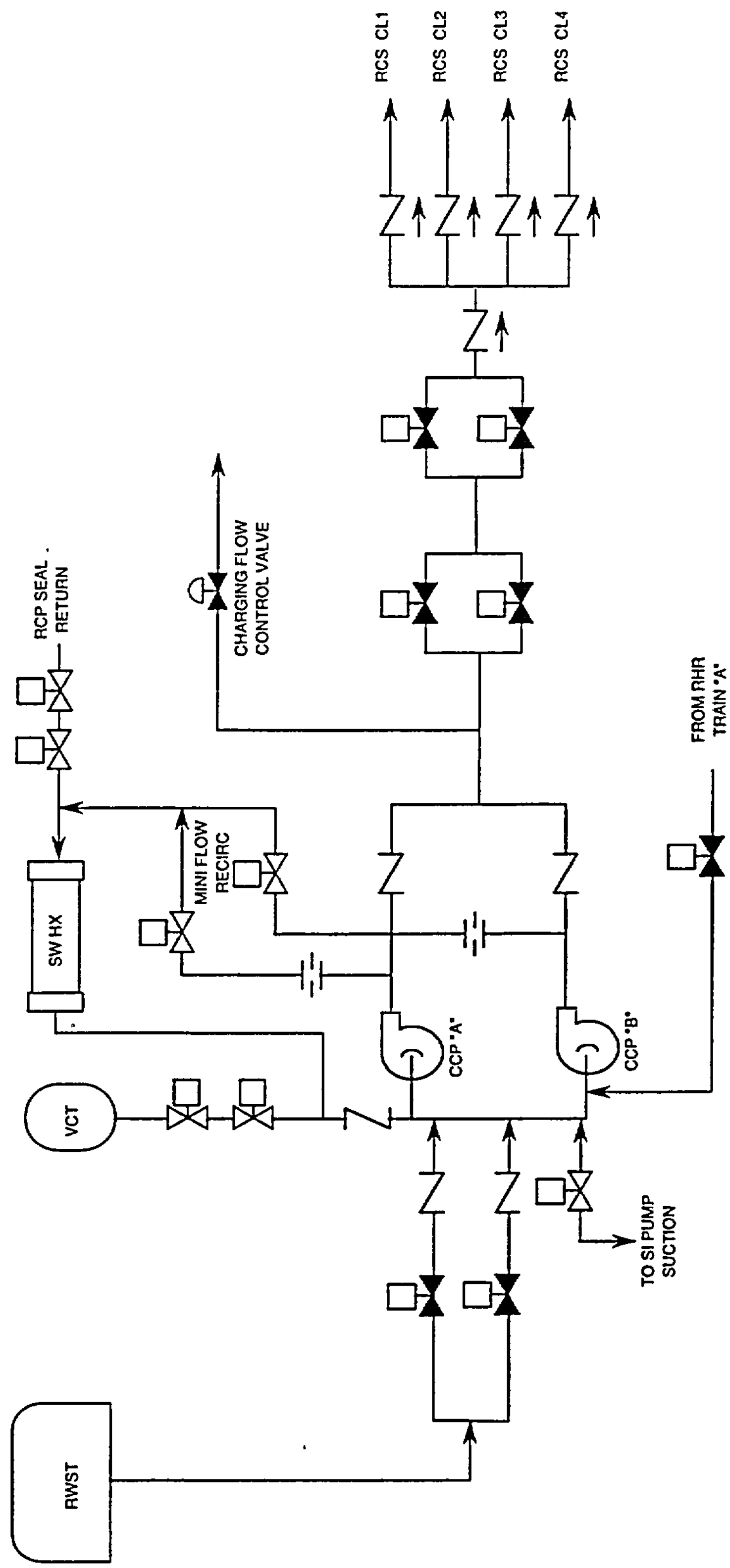

Figure 5.1-6 High Head Injection System

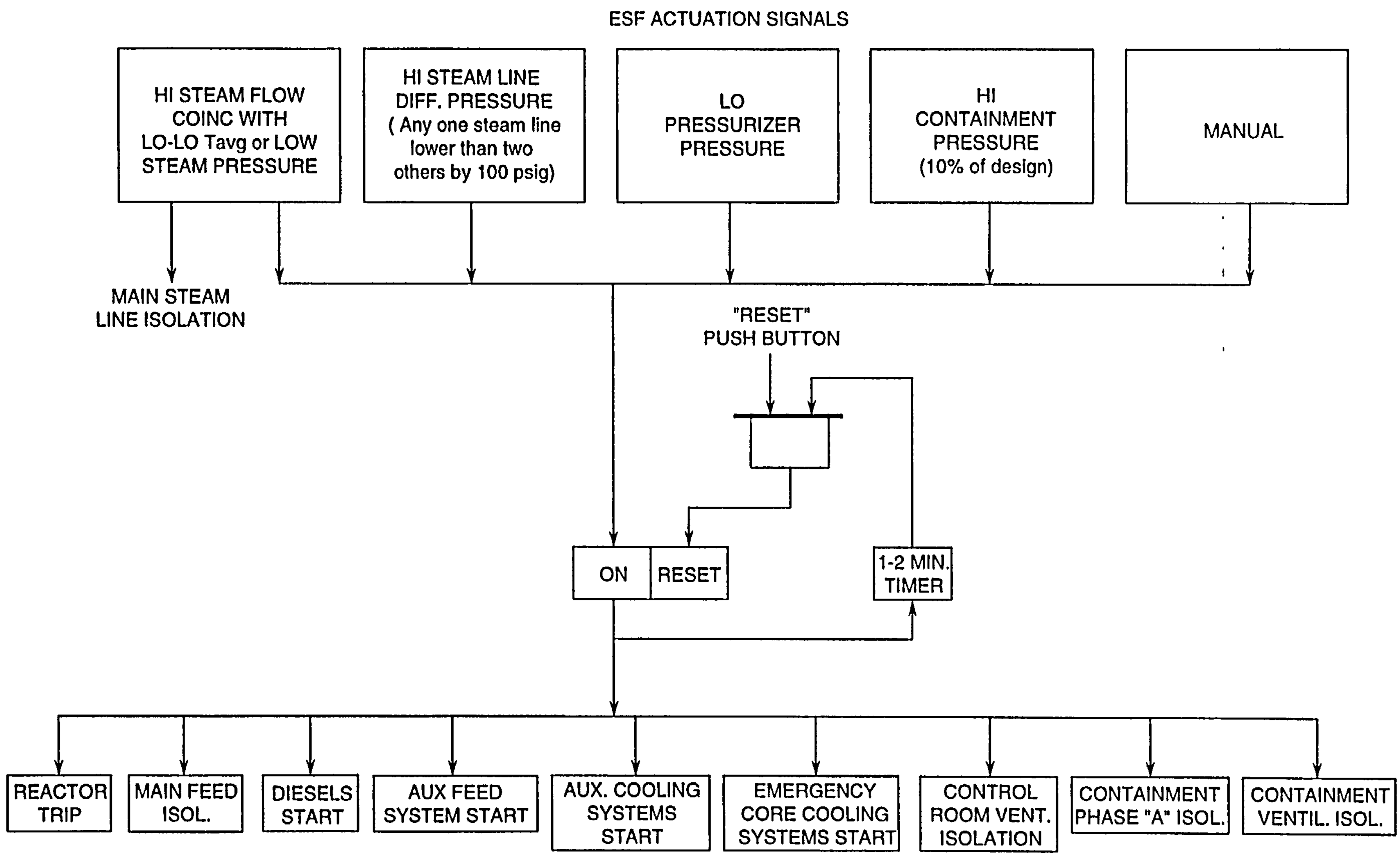

Figure 5.1-7 ESF Actuation Logic

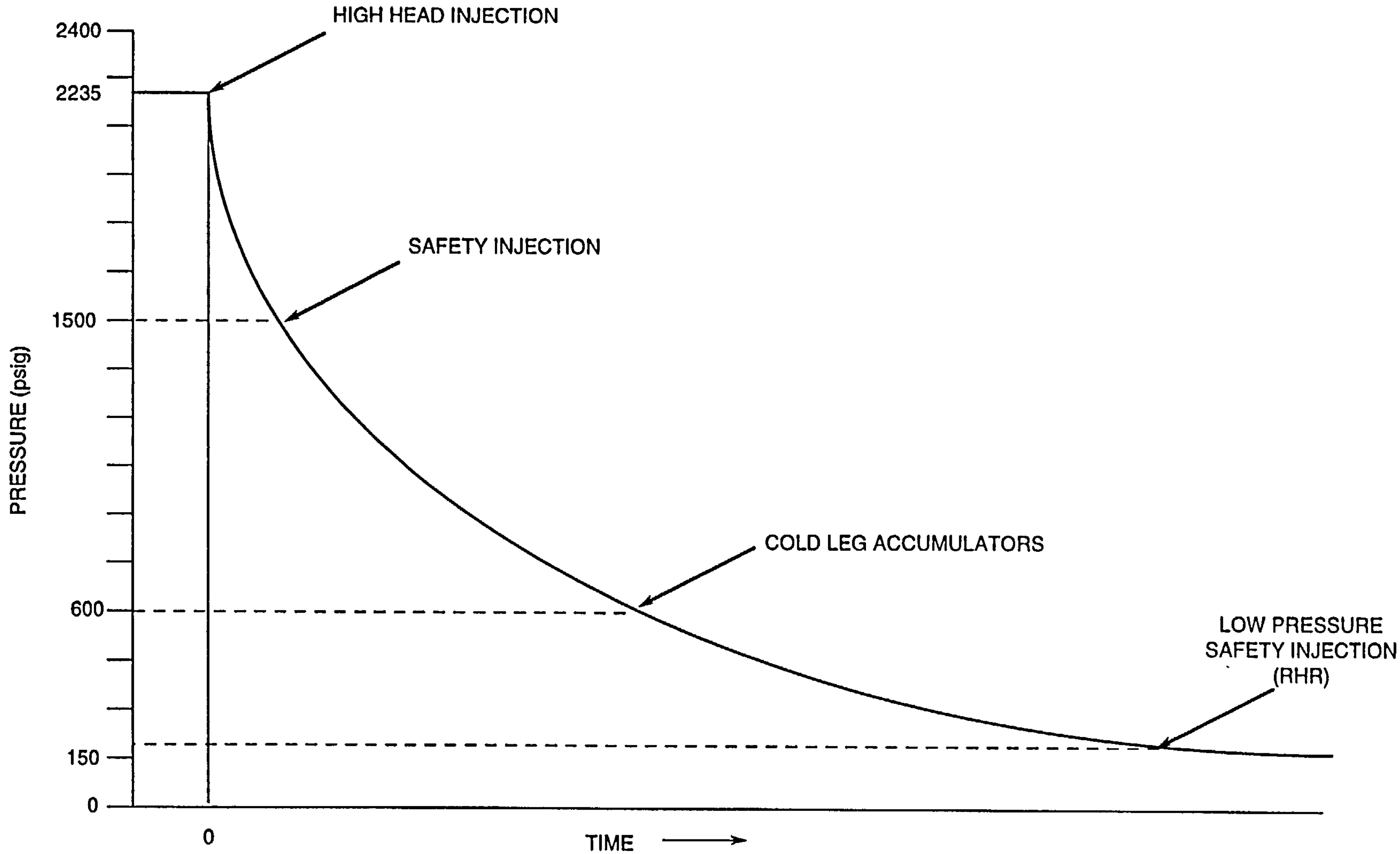

Figure 5.1-8 Slow RCS Depressurization (SBLOCA)

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Westinghouse Technology Manual

Section 5.2

Containment and Auxiliary Systems

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5.2 CONTAINMENT AND AUXILIARY SYSTEMS

Learning Objectives:

1. State the purpose of the containment building.

2. State the purpose of containment isolation during an accident, including:

   a. When isolation occurs,
   b. The types of systems isolated, and
   c. How redundancy of isolation is provided.

3. State the purpose of the containment hydrogen recombiners.

4. State the purpose of the containment fan coolers during accident and non-accident conditions.

5. State the purpose of the containment spray system.

6. Explain why sodium hydroxide is added to the containment spray.

7. List the containment spray system actuation signals.

5.2.1 Introduction

Multiple barriers designed into the power plant provide containment of radioactive products at three fundamental levels:

- Zircaloy tubes,
- Reactor coolant system pressure boundary, and
- The reactor containment vessel (building).

This chapter discusses the design of the reactor containment building that will contain and control any release of radioactivity to the environment under normal or emergency conditions. Also included are containment systems that will protect the integrity of the containment by reducing steam pressure and temperature and controlling hydrogen to avoid an explosive mixture. Ventilation system provided with filters will reduce radioactivity in the containment atmosphere to permit safe access into the containment. The structure provides biological shielding for both normal and accident conditions.

5.2.2 Containment

5.2.2.1 Safety Design Basis

The safety design basis for the containment is that it must withstand the pressures and temperatures of the design basis accident (DBA) without exceeding the design leak rate, as required by 10CFR50, Appendix A, General Design Criterion (GDC) 50.

The engineered safety features (ESF) must ensure that the release of radioactive material due to a design basis accident does not result in doses exceeding the values specified in 10CFR100 with reference to the "exclusion area" and the "low population zone" (Figure 5.2-1).

5.2.2.2 Exclusion Area

The "exclusion area" is *that area surrounding the reactor in which the reactor licensee has authority to determine all activities including exclusion or removal of personnel and property from the area.* The doses received in the exclusion area are defined in 10CFR100 as follows:

A person located at any point on the outer boundary of the exclusion area for two hours immediately following the onset of the fission product release would receive a radiation dose of no more than 25 rem whole body or 300 rem to the thyroid from iodine exposure.

5.2.2.3 Low Population Zone

The "low population zone" is *that area immediately surrounding the exclusion area which contains residents, the total number and density of which there exists a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident.* The doses received in the low population zone are defined in 10CFR100 as follows:

A person located anywhere on its outer boundary who is exposed to the radioactive cloud resulting from a fission product release (during the entire period of its passing) would not receive a total radiation dose of 25 rem whole body or 300 rem (from iodine exposure) to the thyroid.

5.2.2.4 General Description

Several types of containment structure have been designed. Those designs in prevalent use incorporate steel vessels or concrete vessels lined with steel plate. Steel vessels can be cylindrical or spherical in shape. Reinforced concrete vessels, which in some cases may be post-tensioned, are cylindrical with hemispherical domes.

This chapter will describe a typical prestressed concrete containment having a cylindrical shell, a hemispherical dome, and a flat slab base. The containment consists of a prestressed, reinforced concrete, cylindrical structure with a hemispherical dome. The floor of containment is a conventionally reinforced concrete slab with a central cavity and instrument tunnel to house the reactor vessel. A continuous peripheral tendon access galley below the base slab is provided for the installation and inspection of the vertical post-tensioning system (Figure 5.2-2).

The base slab, cylinder, and dome are reinforced by steel bars, as required by the design loading conditions. Additional reinforcement is provided at discontinuities in the structure and the major penetrations in the shell.

The interior of the containment is lined with carbon steel plates welded together to form a barrier, which is essentially leak tight.

The post-tensioning system used for the shell and dome of the containment employs tendons. These tendons are unbonded, each consisting of 170 one-quarter inch, high strength, steel wires and anchoring components. The prestressing load is transferred to steel bearing plates embedded in the structure. The ultimate strength of each tendon is approximately 1000 tons. The unbonded tendons are installed in tendon ducts and tensioned in a predetermined sequence. The tendon ducts consist of galvanized, spiral-wrapped, semi-rigid, corrugated steel tubing designed to resist construction loads. After tensioning, a petroleum based corrosion inhibitor is pumped into the duct.

The post-tensioning system is divided into two sets of tendon patterns. One set consists of 86 inverted U-shaped tendons which extend through the full height of the cylindrical wall over the dome. They are anchored at the bottom of the base slab. The other set consists of 135 tendons forming the circumferential (hoop) tendons. Three buttresses, located 120 degrees apart, extend the full height of the containment. The hoop tendons are anchored to one buttress, extend through the next, and are anchored to the third buttress. Each tendon extend around 240 degrees of the containment building. The hoop tendons extend from ground level to 45 degrees above the spring line (Figure 5.2.-2).

5.2.2.5 Containment Penetrations

The containment penetrations fall into two major categories, large and small. Large penetrations are defined as those having an inside diameter equal to or greater than 10 feet (2.5 times the nominal shell wall thickness). The equipment hatch and the personnel hatch fall into this category.

The equipment hatch is a welded steel assembly with a double-gasketed, flanged, and bolted cover. The penetration inside diameter is approximately 20 feet. A removable missile shield is provided outside of the containment building for the equipment hatch.

One personnel and one auxiliary hatch are provided for the containment. Each hatch has two doors, with double gaskets in series. The doors are mechanically interlocked to ensure that one door cannot be opened unless the second door is sealed. Each door is designed to withstand design containment pressure of 60 psig. Provisions are made to remotely close a door if one is accidentally left open.

To protect the hatches from missiles, the personnel hatch is enclosed in the auxiliary building, and the auxiliary hatch is enclosed in a tornado resistant concrete structure. The auxiliary hatch diameter is approximately 6 feet 4 inches and is, therefore, a small penetration. The personnel access hatch has an inside diameter of approximately 11 feet 3 inches and is considered a large opening (Figure 5.2-3).

A fuel transfer tube penetration is provided to transfer fuel between the refueling canal and the spent fuel pool (Figure 5.2-4). The penetration consists of a 20-inch diameter stainless steel pipe installed inside a 26-inch diameter sleeve. The sleeve is designed to provide containment integrity, allow for differential movement between containment and the fuel building, and prevent leakage through the fuel transfer tube in case of an accident.

Small penetrations include miscellaneous piping, electrical, and ventilation penetrations.

5.2.3 Containment Heat Removal Systems

5.2.3.1 Design Basis

The functional design basis of the containment heat removal system as defined in 10CFR50, App. A, GDC 38, is to reduce the containment temperature and pressure following a loss of coolant accident or main steam line break accident, by removing thermal energy from the containment atmosphere.

5.2.3.2 Containment Heat Removal Subsystems

The containment heat removal system is comprised of the following subsystems:

- Residual heat removal system (Chapter 5.1),
- Containment cooling system, and
- Containment spray system.

The functional performance of the containment spray system is to reduce the containment atmosphere temperature and pressure following a loss of coolant accident or main steam line break. It performs this function by spraying water into containment to absorb the heat.

During the initial phase of containment spray system operation, water is taken from the refueling water storage tank (RWST) which is relatively cool. When the RWST becomes nearly empty, containment spray pump suction is transferred to the recirculation sump. The water in the recirculation sump is cooled by the residual heat removal system through the residual heat removal heat exchangers.

The containment cooling systems performs the same function as does the containment spray system, however it accomplishes this function by recirculating the air in containment through fan coolers. The air is cooled in the fan coolers using service water as a heat sink.

As a result of lowering the containment pressure, the containment leakage rates are reduced (less driving head) and off-site radiation levels are reduced.

5.2.4 Containment Cooling System

5.2.4.1 Design Bases

The safety design bases of the containment fan coolers are:

- Designed to remain functional after a safe shutdown earthquake,
- Safety function can be performed assuming a single active failure coincident with a loss of off-site power,
- Designed to remain functional in an accident environment,
- Active components capable of being tested during normal plant operations, and
- Designed in conjunction with containment spray system to keep containment pressure below design value during a loss of coolant accident or main steam line break in containment.

The ventilation systems play an important role in the operation of the entire plant. These systems filter, mix, heat, and cool the air throughout the plant. They insure a suitable atmosphere for the operators as well as the equipment. The ventilation systems also help reduce radiation levels in the event of a radiological accident.

The containment cooling system (Figure 5.2-5) consists of the containment fan coolers, hydrogen mixing fans, cavity cooling fans, control rod drive mechanism cooling fans, machine room exhaust fan, pressurizer cooling fan, and associated duct works and dampers.

The containment cooling system functional objective during normal operations is to maintain containment atmosphere at a fairly uniform temperature compatible with equipment operation. Limiting equipment include the control rod drive mechanism coils, excore nuclear detectors, primary shield, and reactor vessel support system.

The functional objective of the containment coolers and hydrogen mixing fans during an accident condition is to provide enough cooling, in conjunction with the containment spray system, to keep containment pressure below 60 psig.

5.2.4.2 Containment Fan Coolers

The function of the four containment fan coolers and associated duct work, during normal operation, is to maintain containment temperature at or below 120°F, with any three of the four fan coolers operating. During accident operations, the function is to keep containment temperature low enough, in conjunction with the containment spray system, so that containment pressure remains below 60 psig.

Air is drawn into the containment coolers through the fan and discharged to the steam generator compartments, the pressurizer compartment, the instrument tunnel, and outside the secondary shield in the lower areas of containment.

The containment coolers are finned-tube type coolers supplied by service water. Service water flow during normal operation is 1100 gpm, and during accident conditions it is 2000 gpm.

Normally all four fans are running in fast speed. During an accident condition, the safety injection signal will cause the fans to shift to slow speed. The shift is done because in a high pressure, high density atmosphere (due to steam in containment), high speed fan operation could cause a motor overcurrent condition.

5.2.4.3 Hydrogen Mixing Fans

The four hydrogen mixing fans are each located on top of a reactor coolant pump access hatch, which is part of a steam generator compartment. The fans draw the relatively cool air in the steam generator compartment and throw it towards the top of containment. This establishes a flow pattern in containment (from the containment fan coil units to the steam generator compartment then towards the top of containment and down again to the coolers). Thus the hydrogen mixing fans, during normal operations, provide a nearly uniform air temperature in containment.

Normally, all four fans are operated in fast speed. During an accident condition, the safety injection signal will shift the fans to slow speed, to prevent overload in a high pressure, high density environment. In slow speed, two out of four fans operating will be sufficient to produce a nearly uniform distribution of hydrogen throughout containment.

5.2.4.4 Control Rod Drive Mechanism Cooling Fans

The control rod drive mechanism (CRDM) cooling fans take a suction from the sides of a shroud that surrounds the CRDM area above the head of the reactor and discharges the air into a plenum, where the air is directed to the containment fan coolers. Cool air from containment atmosphere is drawn over the CRDMs through the top of the shroud. The purpose of the CRDM cooling fans is to limit ambient temperature in the shroud to 170°F for protection of the CRDM coils.

The fans are powered from safety related busses, but they are not safety related. This gives the option on a loss of off-site power to run the fans if the extra power is available.

Normally three of the four fans are running. Each fan has a discharge damper that operates in conjunction with the fan so that when one fan is idle, the air flow will not short circuit through it. There is also a damper in each line from the discharge plenum to the containment fan coolers. When a containment fan cooler is not operating, the damper in its duct work is shut.

5.2.4.5 Cavity Cooling Fans

Two cavity cooling fans, one of which is normally running, take a suction on a plenum which draws air from a header surrounding the reactor vessel primary shield. This suction header has a series of ducts connecting at intervals around the primary shield. Some of these lines penetrate the primary shield and connect to each excore nuclear detector well.

Air is drawn from the area surrounding the reactor to cool the nuclear detector, which is limited to 135°F during normal operations.

The other ducts penetrate the primary shield above and below the area of the reactor coolant system piping penetrations of the primary shield. The suction from these ducts draws air in through the gaps between the reactor coolant system piping and the primary shield and up from the instrument tunnel. These air flows are designed to cool the reactor vessel support system and limit ambient temperature around the reactor vessel so that the inner primary shield wall concrete temperature is limited to 150°F during normal operation. The cavity cooling system performs no safety function.

5.2.4.6 Pressurizer Cooling Fan

The pressurizer cooling fan takes a suction in the lower area of the pressurizer compartment and discharges it near the heater connections to keep them cool when containment fan cooler "D," which normally supplies the pressurizer compartment, is out of service.

5.2.4.7 Containment Cooling Flow Paths

The normal flow paths for the containment cooling systems are:

- All four containment fan coolers operating and discharging cool air to the lower portions of containment outside of the secondary shield and to the four steam generator compartments, the pressurizer compartment, and the instrument tunnel,

- The four hydrogen mixing fans taking suction on the steam generator compartments and discharging high in the containment,

- The cavity cooling fans taking suction inside the primary shield wall (including instrument tunnel) and discharging upward into containment, and

- The air high in containment will fall, because of air currents generated by the fans, and be drawn into the containment coolers.

The CRDM cooling fans will take a suction on the shroud surrounding the area above the reactor vessel head and discharge this hot air to the containment coolers

Upon receipt of a safety injection signal, the four hydrogen mixing fans and the four containment fan coolers will shift to slow speed. The essential service water flow supplied to the containment coolers increases from 1100 gpm to 2000 gpm for extra cooling. The CRDM cooling fans will stop. The other fans will continue to operate as long as power is available. However, only the hydrogen mixing fans and the containment cooler fans are required to be running to achieve the containment cooling system safety function.

5.2.5 Containment Spray System

The containment spray system consists of two 100 percent capacity trains of equipment (Figure 5.2-6). The system operates in two modes. The injection mode flow path takes a suction from the refueling water storage tank, to the containment spray pumps where sodium hydroxide (NaOH) is mixed with the refueling water storage tank water, and delivers to the containment spray headers. The recirculation mode flow path takes a suction from the recirculation sump, to the containment spray pumps where NaOH is mixed in if any is left over from the injection mode, delivering water to the spray headers.

Each train consists of a containment recirculation sump, a containment spray pump, a spray additive eductor, and a series of spray headers and nozzles. Common to both trains are the refueling water storage tank and the spray additive tank. The containment spray system serves no function during normal plant operations, only operating during an accident which results in high containment pressure.

5.2.5.1 Containment Spray System Design

The containment spray system is an engineered safety features (ESF) system. It is a subsystem of both the containment heat removal system and the fission product removal and control system. As an ESF system, it is safety related. The system safety design bases are:

- The containment spray system is protected from natural phenomena such as earthquakes, tornadoes, and flooding.
- The containment spray system will perform its design functions while sustaining a single active failure coincident with a loss of off-site power.
- Provisions are made for component testing during plant operations.
- Component isolation to combat leakage is built into the containment spray system. The containment spray system, in conjunction with the other containment heat removal systems, is capable of removing enough heat following a postulated accident to keep containment pressure below its design value. The containment spray water does not contain substances that would be unstable in a post loss of coolant accident environment, or would cause extensive corrosion of equipment, or release of combustible gas in containment.
- The containment spray system will provide a spray solution in the pH range of 9.5 to 11.0 and a final recirculation sump pH of at least 8.5.
- The containment spray system is capable of reducing iodine and other fission product concentrations in containment such that off-site radiation doses are within the guidelines of 10CFR100.

Among the above safety design bases are the two functional objectives of the containment spray system. These are:

- Reduce containment pressure and temperature following a loss of coolant accident or steam break in containment to less than 60 psig.

- Limiting off-site radiation levels to within the guidelines of 10CFR100.

Pressure control in the containment is accomplished as the system spray cool refueling water storage tank water over the large containment volume. The water absorbs heat and condenses the steam present from a loss of coolant accident or steam break. A loss of coolant accident will cause the release of radioactive iodine gas, a fission product of great concern. The sprayed water absorbs the radioactive iodine gas. Sodium hydroxide is added to the sprayed water to increase its pH.

The containment spray system has built in redundancy, with two 100 percent capacity trains. In addition to being able to accept an active failure during the injection mode of containment spray system operation, it can accept an active or passive failure during the recirculation mode and still perform its designed function.

5.2.5.2 Containment Spray System Description

During normal operations, the containment spray system is lined up to take a suction from the refueling water storage tank through a normally open motor operated isolation valve.

The containment spray pumps are vertical centrifugal pumps driven by 500 hp motors. The pump components are designed for 450 psig and 300°F. The pumps will automatically start on a containment spray actuation signal (CSAS), an increased pressure in containment of 27 psig. The containment spray pumps may be manually controlled from the main control board.

Containment spray piping penetrates the containment wall and water is discharged to the containment atmosphere through headers and nozzles located high in the containment building dome.

There are 197 hollow cone type spray nozzles per train. Each has a 0.44 inch throat opening and sprays 15.2 gpm with a 40 psi pressure drop. The spray nozzles will produce an average drop size of 1000 microns, thus increasing the available spray surface area. These nozzles are arranged in half-ring headers (Figure 5.2-7) in the dome of containment. The nozzles are arranged on the headers such that one train of the containment spray system will cover at least 90 percent of the operating deck level of containment with spray.

The spray additive portion of the containment spray system consists of the spray additive tank and the spray additive eductors. Approximately 5 percent of the flow from the discharge of each containment spray pump is diverted into the spray liquid jet eductors. The eductors use the kinetic energy of the diverted water to entrain the proper amount of sodium hydroxide solution. The sodium hydroxide solution discharges into the suction of the containment spray pumps and is mixed with the main flow path.

The spray additive tank is a 4700 gallon tank containing 30 percent by weight sodium hydroxide. The tank is made of stainless steel with a baked phenolic coating inside to prevent highly corrosive caustic attack. The tank is designed to withstand 15 psig internal pressure and 1 psig external pressure.

When the refueling water storage tank low level condition occurs, the operator will shift the containment spray system from injection mode to recirculation mode. This is accomplished by resetting the containment spray actuation signal and opening the containment recirculation sump isolation valves and shutting the refueling water storage tank isolation valves.

The flow path is from the containment recirculation sump, through the spray pumps, to the spray header. In this mode, the spray system continues to absorb fission products, but its cooling capacity is reduced since it is using sump water, which is hotter than the water from the refueling water storage tank. It will basically keep containment atmosphere in equilibrium with the sump temperature.

The containment recirculation sumps are two redundant sumps located outside of the secondary shield wall at the lowest elevation in containment, exclusive of the reactor cavity. The sump (Figure 5.2-8) is about 8 feet deep and 8 feet square and is covered. The covering consists of a housing with a series of screens on the sides, and the top is a concrete slab. Three sets of screens make up the side of the housing and are sized differently. A grating on the outside of 1/2 x 3 inch bars (maximum 2.5 inch opening), a coarse screen is in the center (maximum 1/2 inch opening), and a fine screen is on the inside (maximum 1/8 inch opening). These screens serve to keep debris from entering the containment spray system and the residual heat removal system. The screens are bolted to a 6 inch curb which surrounds the sump and prevent high density particles from entering it.

The residual heat removal and containment spray system suction lines penetrate the sump near the bottom at a horizontal angle. This helps prevent vortexing in the sump. The lines slope slightly downward to prevent trapping air in the line. The containment isolation criteria requires that guard piping surround the suction piping and the containment isolation valve. Therefore, one passive failure will not cause containment leakage.

5.2.6 Containment Isolation

5.2.6.1 Design Bases

The containment isolation system allows the normal or emergency passage of fluids through the containment boundary while minimizing the release of fission products from containment following a loss of coolant accident or fuel handling accident. 10CFR50, App. A, GDC 54, requires that piping systems penetrating containment have an isolation system. These systems are divided into three general categories as follows:

1. Reactor coolant pressure boundaries penetrating containment (10CFR50, App. A, GDC 55) must isolable by one of the following methods:
    - One locked closed isolation valve inside and outside containment,
    - One locked closed isolation valve inside and one automatic valve outside containment,
    - One automatic valve or check valve inside and one locked closed isolation valve outside containment, or
    - One automatic valve or check valve inside and one automatic valve outside containment.

(NOTE: A check valve vs. an automatic valve may be used inside containment but not outside containment.)

2. Primary containment isolation (10CFR50, App. A, GDC 56) is defined as penetrations to the containment atmosphere.

3. Closed system isolation valves (10CFR50, App. A, GDC 57) covers all penetrations not covered previously (e.g., component cooling water). The valve requirements are that the penetration line will have at least one isolation valve which is either automatic or locked closed or is capable of remote manual isolation. These valves will be located outside containment.

5.2.6.2 Phase A Isolation

A containment phase A isolation (CISA) signal serves to isolate containment in the event of a loss of coolant accident or steam break. This signal actuates closure of all valves that are not required to be open for the operation of essential equipment. A CISA actuation signal originates with a safety injection or manual actuation.

5.2.6.3 Phase B Isolation

A containment phase B isolation (CISB) signal serves to isolate containment on a steam break or loss of coolant accident. It isolates penetrations that were not isolated by the CISA signal and which are not required for operation of the engineered safety features equipment. In particular, this isolates component cooling water to the reactor coolant pumps.

5.2.6.4 Containment Purge Isolation

A containment purge isolation system (CPIS) detects any abnormal amount of radioactivity in the containment atmosphere or in the containment purge effluent and initiates appropriate action to ensure that any release of radioactivity to the environment is controlled. This appropriate action is shutting the purge system isolation valves and deenergizing the purge system fans. The CPIS protects against activity release following a loss of coolant accident or fuel handling accident.

5.2.6.5 Main Steam Line Isolation

One engineered safety feature function of a main steam line isolation is to isolate the main steam lines in the event of a loss of coolant accident. However, its primary function is to isolate the main steam lines in the event of a main steam line break.

5.2.6.6 Main Feedwater Line Isolation

A main feedwater line isolation signal isolates the main feed lines in the event of a loss of coolant accident. This system actuates on a safety injection signal, a high water level condition in the steam generators (designated P-14 and occurring at 78% narrow range level), a reactor trip (P-4) coincident with 2 out of 4 loops of T_{avg} 564°F, and manually.

5.2.7 Containment Combustible Gas Control System

5.2.7.1 Design Basis

General Design Criterion 41 of 10CFR50, App. A, requires that oxygen, hydrogen, and other substances in containment be controlled to preserve containment integrity. The containment combustible gas control system is designed under this criteria to control hydrogen.

The safety design basis of the containment combustible gas control system is to maintain hydrogen concentration below 4.0 percent by volume in containment while not exceeding the guideline values of 10CFR100 as to general population radioactivity exposure.

5.2.7.2 Hydrogen Sources

The sources of hydrogen in containment are:

- Zirconium-water reaction,
- Radiolytic decomposition of water, and
- Metal corrosion in post loss of coolant accident environment (i.e., sodium hydroxide attacks aluminum and boric acid attacks zinc, both generating hydrogen).

5.2.7.3 Hydrogen Recombiners

Hydrogen recombiners are the primary means of reducing hydrogen concentration in containment. The hydrogen recombiners are devices that heat the air to the point where hydrogen and oxygen will recombine. They are manually actuated from the main control board when hydrogen concentration reaches a predetermined value and are normally turned on one day after the occurrence of a loss of coolant accident.

The two hydrogen recombiners are passive electrical devices located on the operating deck of the containment (Figure 5.2-9). Only one hydrogen recombiner is necessary to maintain hydrogen concentration below 4 volume percent.

Hydrogen recombiners operate using natural circulation. The air is heated by electric heaters to about 1150°F, at which point oxygen and hydrogen will combine to form water. The air/water mixture is then mixed with containment air and exhausted out the top. The recombiners are constructed so that containment spray water will not inhibit their operation.

5.2.7.4 Hydrogen Monitoring System

The hydrogen monitoring system provides operators with indication of the containment hydrogen concentration.

5.2.7.5 Hydrogen Mixing Fans

The hydrogen mixing fans will operate in slow speed during accident conditions to ensure uniform hydrogen distribution in containment. Only two of the four fans are needed for this purpose. The fans provide mixing of the containment atmosphere to prevent hydrogen pocketing. Hydrogen pocketing could produce an explosive mixture (4 - 74 volume percent) in a local area.

5.2.7.6 Hydrogen Purge System

The hydrogen purge system is a backup to the hydrogen recombiners. This system is designed to purge the containment atmosphere through the fuel/auxiliary building emergency exhaust system to reduce the hydrogen concentration in containment and not exceed the 10CFR100 dose limits outside of containment.

The hydrogen purge system consists of two containment isolation valves and duct work that delivers containment air to the auxiliary fuel building emergency exhaust system. The hydrogen purge system would not be required unless there was a failure of both hydrogen recombiners. If required, it would be manually initiated after a loss of coolant accident and when a complete plant status evaluation has been performed.

Makeup air to the containment would be provided by the instrument air penetrations or an air bottle that could be hooked up to several containment penetrations. The time and duration of the purges will be determined by operational conditions and environmental conditions.

5.2.8 Fission Product Removal and Control Systems

5.2.8.1 System Function

The fission product removal and control systems function to reduce or limit the amount of fission products released following a loss of coolant accident or fuel handling accident. The systems involved are the containment systems, containment spray system, the emergency exhaust system, and the control building ventilation system.

Another function of the containment spray system is to remove fission products from the containment environment. The safety design basis of the containment spray system with respect to the fission product removal and control system is that it is capable of reducing the iodine and particulate fission product inventories in the containment atmosphere such that the off-site exposures resulting from a design basis loss of coolant accident are within the requirements of 10CFR100.

The normal properties of water which pertain to particulate absorption are enhanced by increasing the pH of the spray water (9.5 - 11.0) by adding 30 weight percent sodium hydroxide. This solution is added to increase the absorption of radioiodine as a result of a chemical reaction to change the iodine into nonvolatile forms.

5.2.8.2 Emergency Exhaust System

The emergency exhaust system is shared by the fuel and auxiliary buildings. The system consists of fans and emergency exhaust filter trains.

The system serves to limit radioactivity release in the event of a loss of coolant accident or fuel handling accident to within the exposure guidelines of 10CFR100 by isolating the auxiliary and fuel buildings and processing their atmospheres through the emergency exhaust trains. The emergency exhaust system automatically isolates the fuel building on high activity level in the fuel building and automatically isolates the fuel and auxiliary buildings on a safety injection signal.

5.2.8.3 Control Building Ventilation System

The control building ventilation system consists of a supply system, a clean area exhaust system, a potentially contaminated area exhaust system, plus several recirculation type cooling systems. The function in normal operations is to provide equipment and personnel in the control room area with the proper environment for operation.

During an accident situation, a control room ventilation isolation signal (CRVIS) isolates the control room and puts the cooling systems in an internal recirculating mode. A filtration process commences to remove any potential contamination. The control room air is pressurized to ensure any leakage is out of the control room, not in. These actions ensure a proper environment in the control room. Personnel in the control room will receive no more than 5 rem whole body dose during the entire accident.

5.2.9 Containment Hydrogen Control System

The containment hydrogen control system consists of the hydrogen mixing fans, the hydrogen recombiners, the hydrogen monitoring system, and the hydrogen purge system (Figure 5.2-10). The hydrogen control system is a member of the combustible gas control engineered safety features system.

The safety design bases applicable to the hydrogen control system are:

- Designed to withstand natural phenomena including a safe shutdown earthquake,
- All components are redundant except for the hydrogen purge system,
- Designed to be capable of maintaining hydrogen concentration below 4.0 volume percent,
- The hydrogen purge system as a backup to the hydrogen recombiners is capable of maintaining hydrogen concentration below 4.0 volume percent while keeping doses to the public below 10CFR100 guidelines,
- Hydrogen mixing fans prevent hydrogen pocketing in containment, and
- Hydrogen monitoring system will provide the operator with containment hydrogen concentration.

The hydrogen control system serves no non-safety related function except the hydrogen mixing fans which are a part of the containment cooling.

5.2.10 Containment Atmosphere Control System

The containment atmosphere control system consists of two 50 percent trains of filter absorber units and fans (Figure 5.2-10). It functions to reduce radioiodine and particulate concentrations during containment entry and during purge operations to reduce releases from containment below levels of 10CFR50, App. I.

The containment atmosphere control system has one filter/absorber bed per train. Each filter/absorber unit consists of:

- 8 moderate efficiency particulate filters,
- 8 HEPA filters,
- 1900 pounds of charcoal, and
- 8 more HEPA filters.

The differential pressure across each filter assembly is measured and is available from the plant computer. The charcoal bed differential pressure is measured and used to control a damper that ensures a constant air flow. The atmosphere control trains are operated periodically, prior to containment entry or prior to purge operation.

5.2.11 Containment Purge System

The containment purge system consists of the purge supply unit, the mini-purge supply unit, the purge filter absorber, train, the purge exhaust unit, the mini-purge exhaust unit, and associated dampers and controls (Figure 5.2-10). The mini-purge system is used during plant operations to reduce the nobel gas concentration, and the purge system is used during plant shutdown to provide ventilation and heating or cooling.

5.2.11.1 Mini-Purge System

The mini-purge supply unit takes a suction on outside air from a plenum on top of the auxiliary building through two isolation dampers. The mini-purge supply system taps into the shutdown purge supply system, and both enter containment via a single 36" duct (this reduces the number of containment penetrations).

Inside containment, the mini-purge supply system separates from the shutdown purge system again. Air will flow from the separation point through a containment isolation damper. The flow passes through a screen that prevents blockage of the containment isolation valve. On the outlet of the screen is a isolation damper that is positioned from the main control board and operates in conjunction with the suction isolation damper of the mini-purge exhaust system.

The mini-purge exhaust fan takes a suction on containment via a similar flow path as the supply unit discharges to containment.

5.2.11.2 Shutdown Purge System

The containment shutdown purge system has a similar flow path as the mini-purge system. It uses different supply and exhaust units and containment isolation valves. This unit is used during plant shutdown conditions for ventilation and conditioning of the air.

The shutdown purge supply unit takes a suction from the same plenum as the mini-purge system, using the same isolation valves. The supply unit consists of a low efficiency filter, cooing coils, heating coils, and a fan. The heating and cooling coils are operated to maintain containment temperature between 50°F and 90°F. The air is discharged to containment through two containment isolation valves that shut in 10 seconds on a containment purge isolation signal.

The shutdown purge exhaust fan takes a suction on containment through two containment isolation valves that operate from the main control board and shut in 10 seconds on a containment purge isolation signal. The flow then proceeds through the same filter/absorber unit described in the mini-purge section, however in this case, charcoal bed differential pressure is used to position a flow control damper to establish a constant flow rate. The only safety related portions of the system are the containment isolation valves and associated containment penetrations.

5.2.12 Summary

The concept of engineered safety features is to retain the fission products in the fuel, reactor coolant, or containment and to reduce to as low as practicable any leakage to the environment from these boundaries. This is accomplished by designing engineered safety features systems to protect the fuel cladding, ensure containment integrity, and limit fission product releases to the environment to within the guideline values of 10CFR100.

The NRC evaluates power reactor site acceptability from three criteria. These are reactor and engineered safety features design, population density and characteristics of the area surrounding the site, and the physical characteristics of the site. The plant's Technical Specifications address regulatory statements that apply to these criteria, specifying acceptable performance.

The containment, in conjunction with its engineered safety features systems, serves to contain fission products released from the fuel and reactor coolant, and to reduce any possible leakage by lowering containment pressure to as low a value as possible and reducing the possibility of containment pressure spikes by keeping hydrogen concentration below the combustible limit.

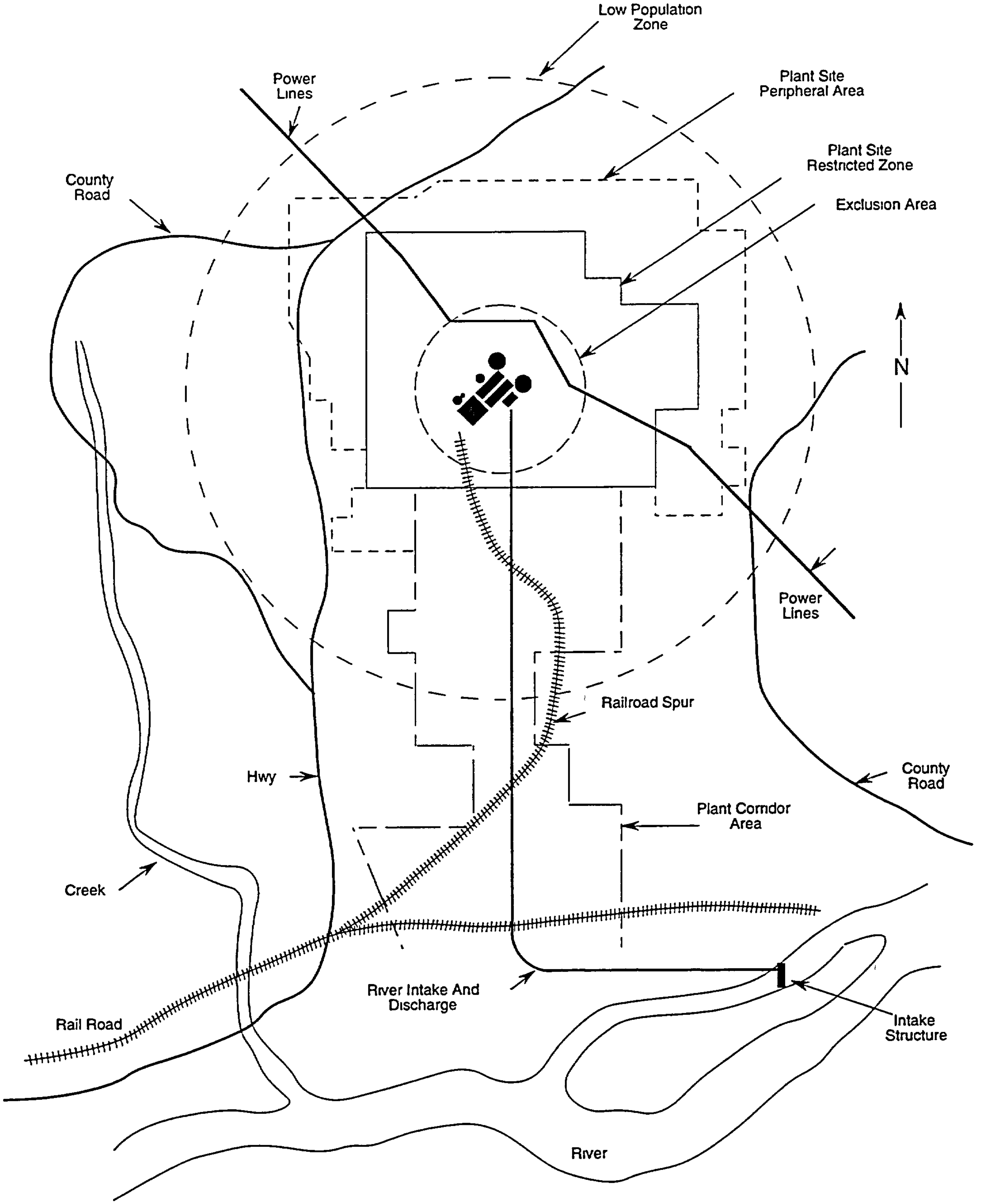

Figure 5.2-1 Typical Site Layout

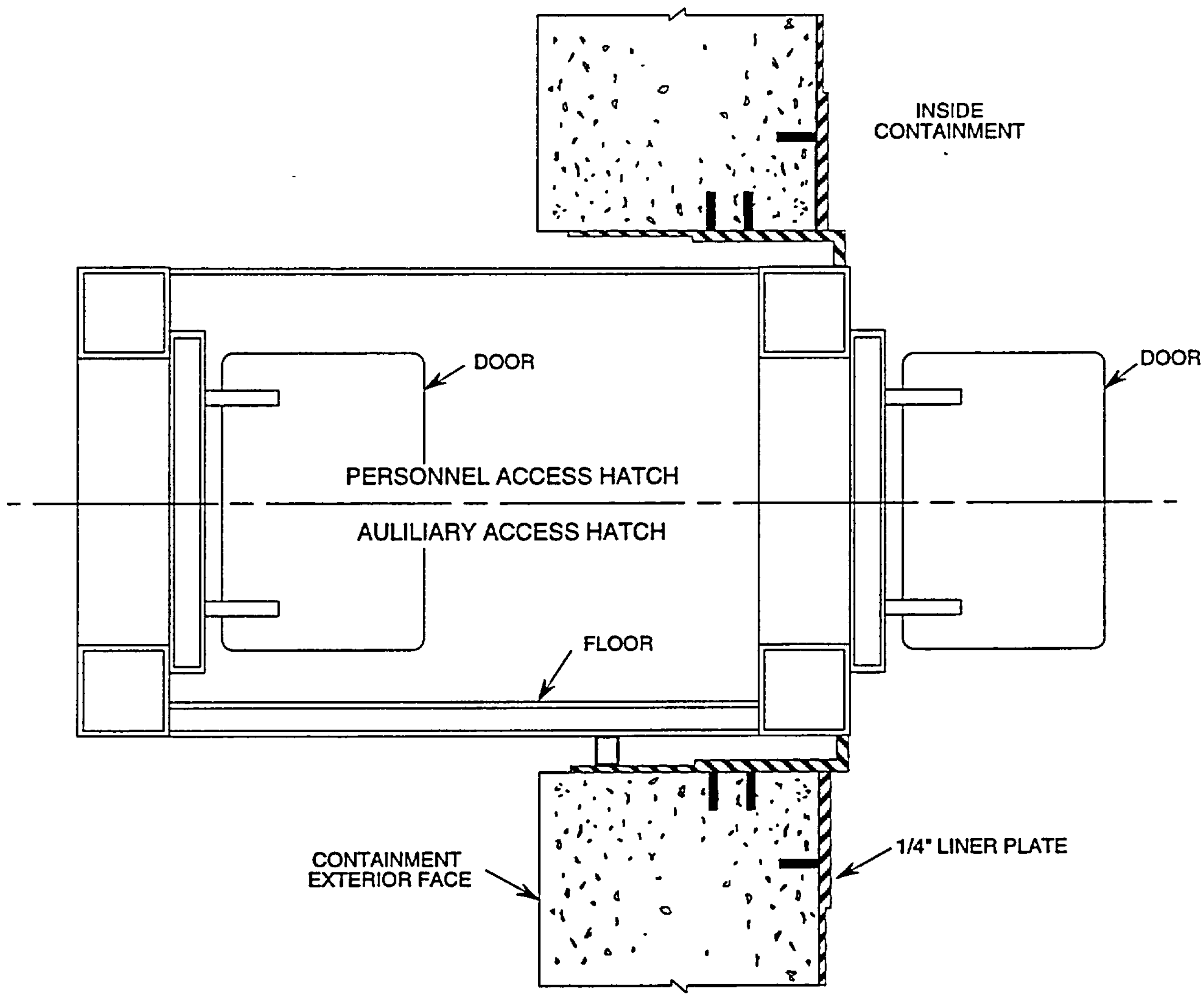

Figure 5.2-3 Personnel Access Hatch

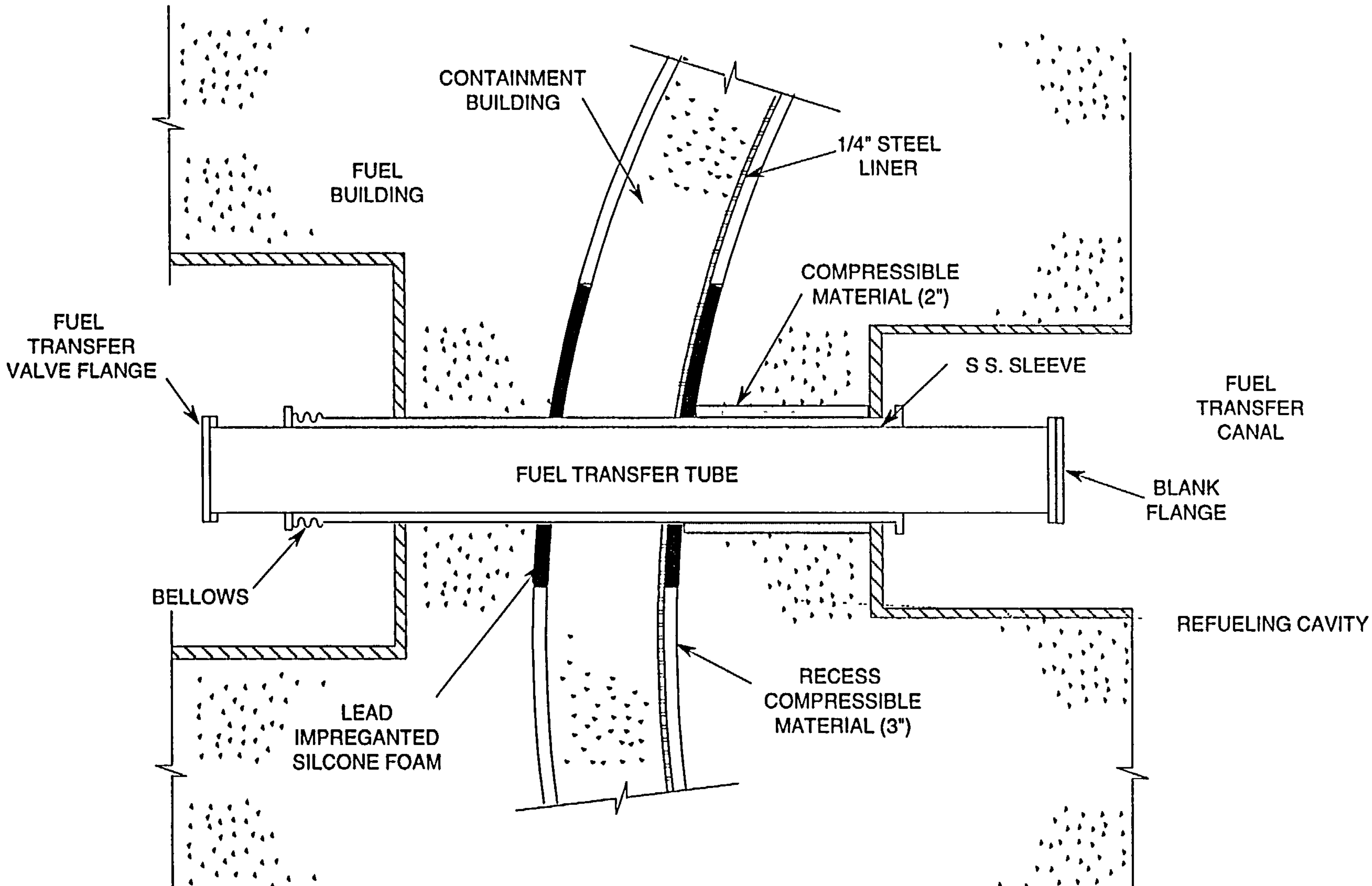

Figure 5.2-4 Fuel Transfer Tube

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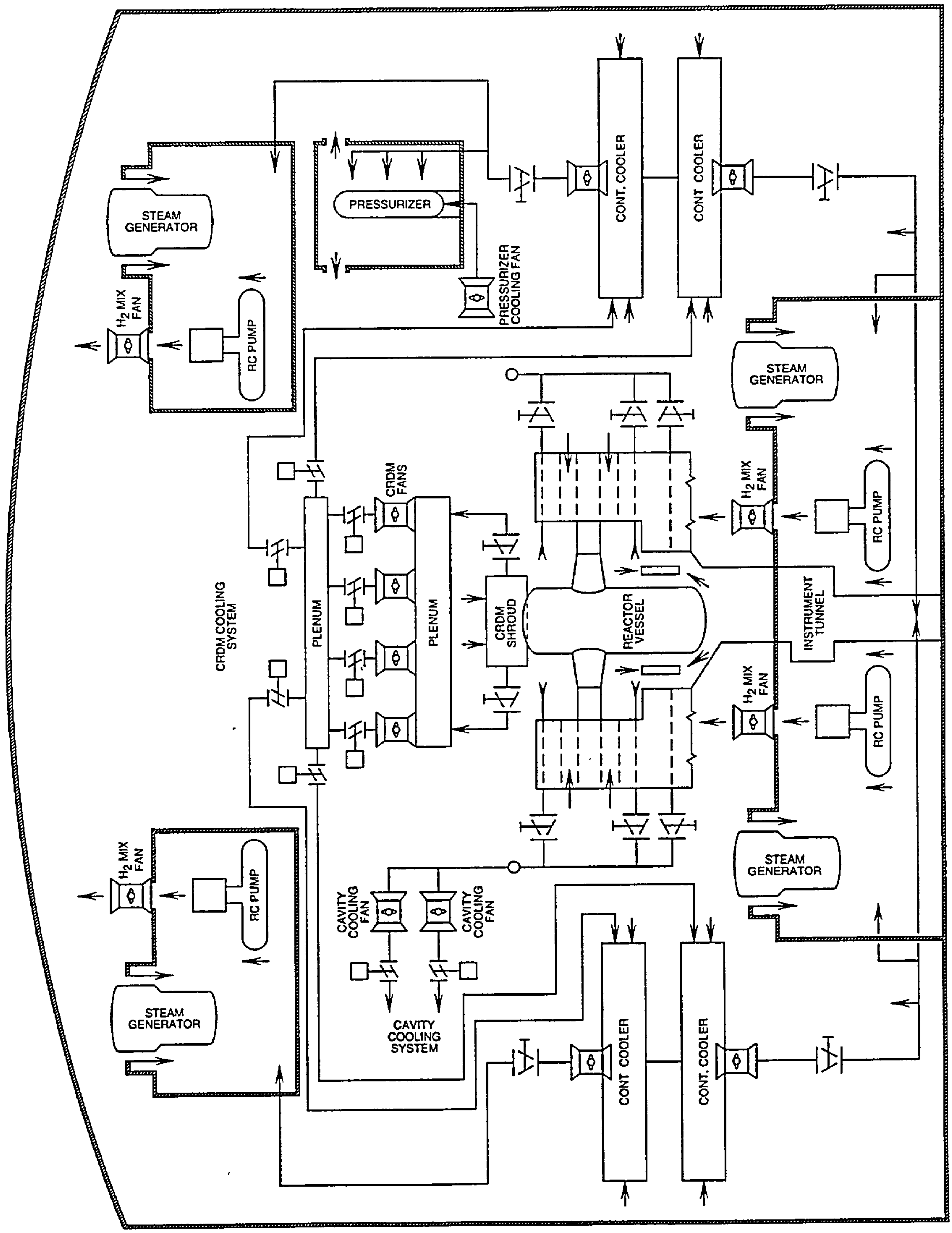

Figure 5.2-5 Containment Cooling

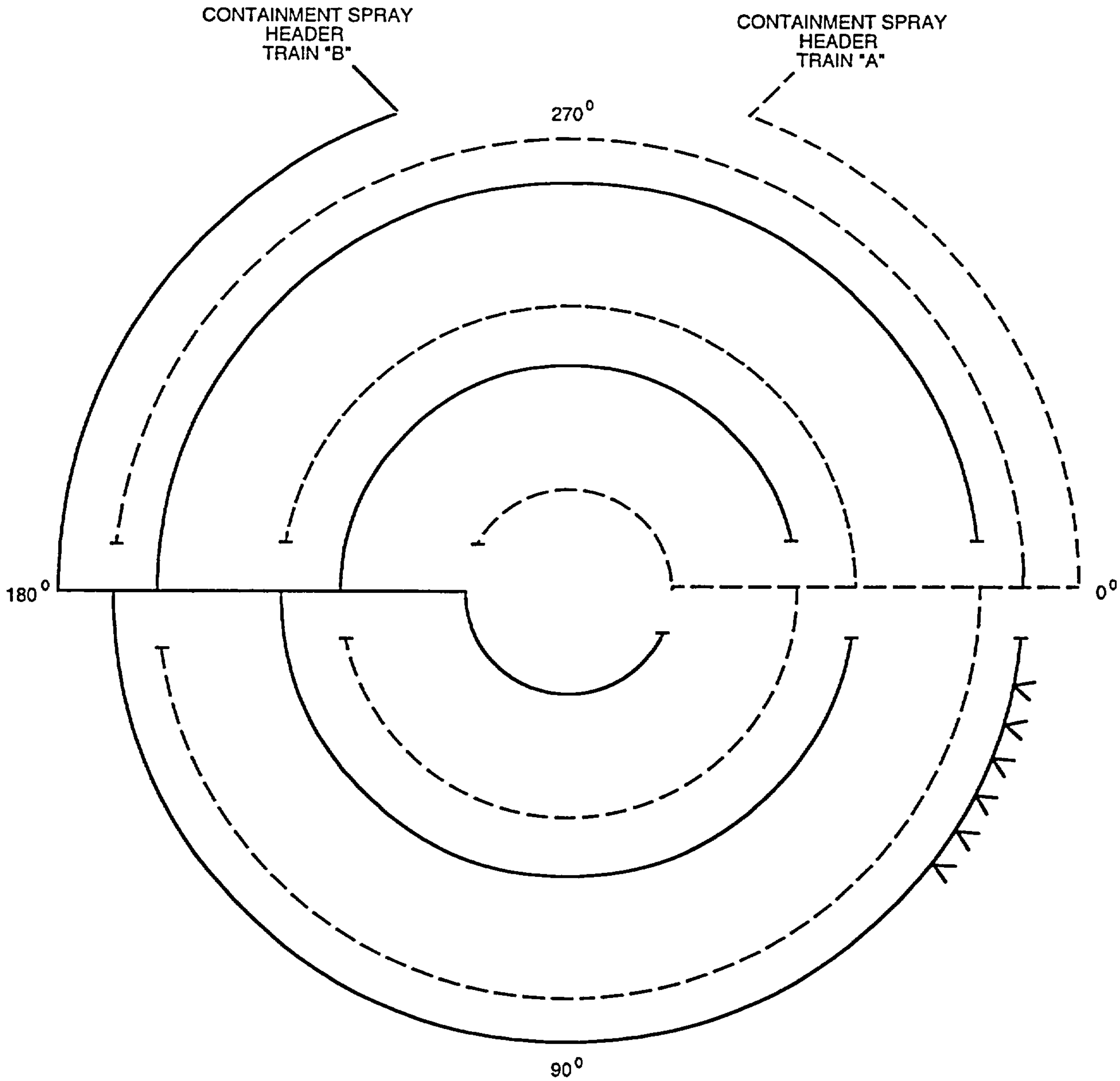

Figure 5.2-7 Spray Header Arrangement

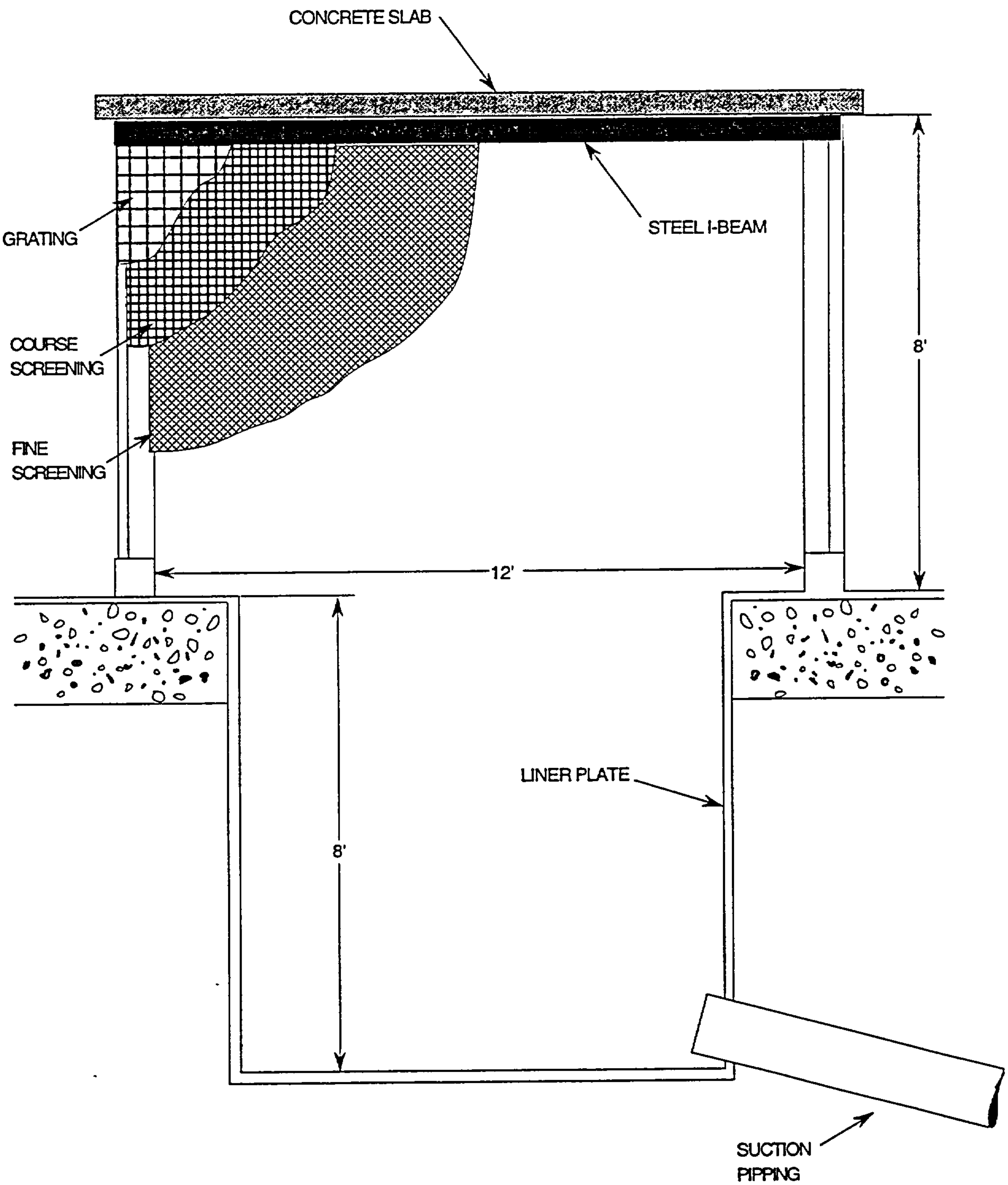

Figure 5.2-8 Containment Recirculation Sump

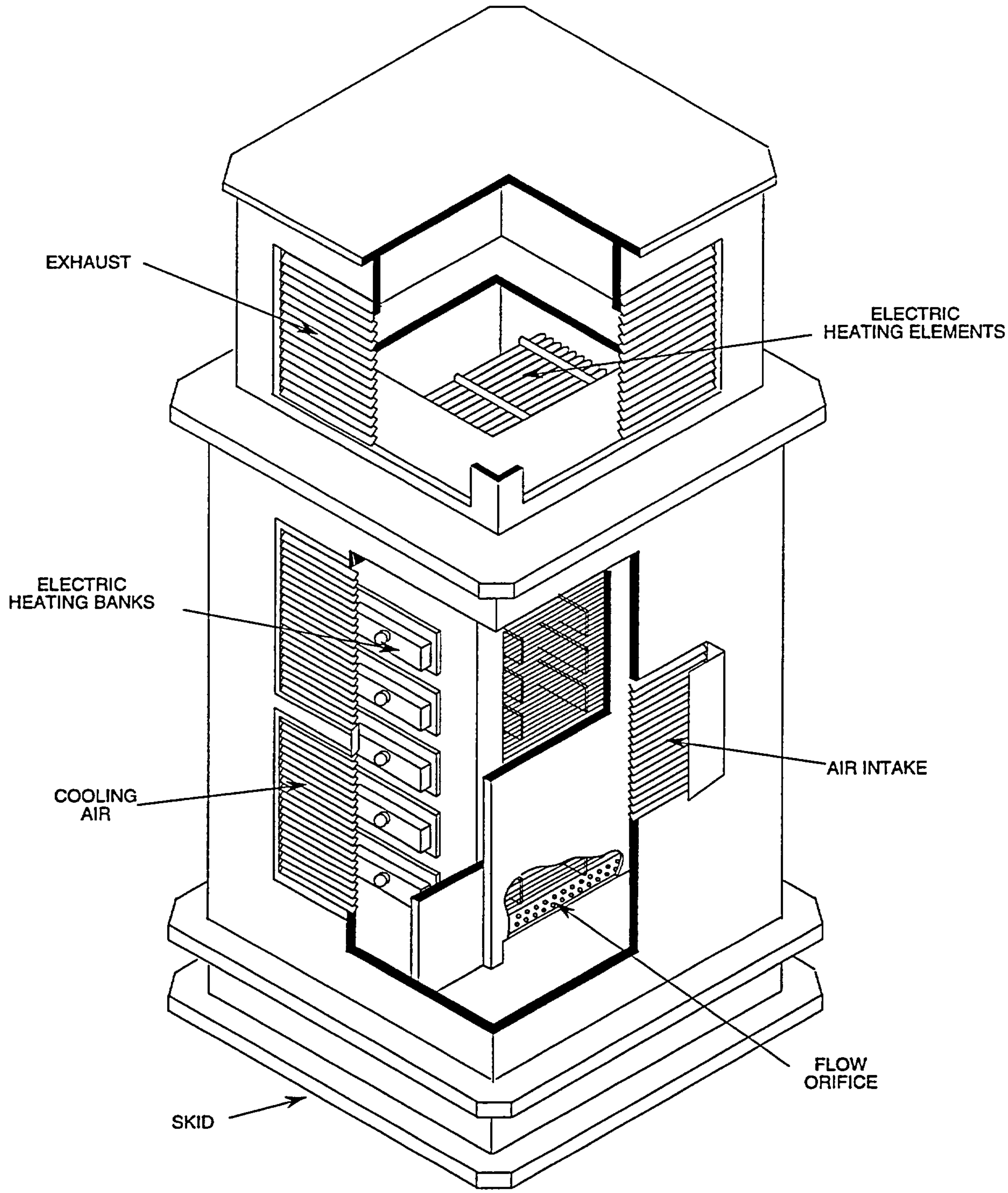

Figure 5.2-9 Electric Hydrogen Recombiner

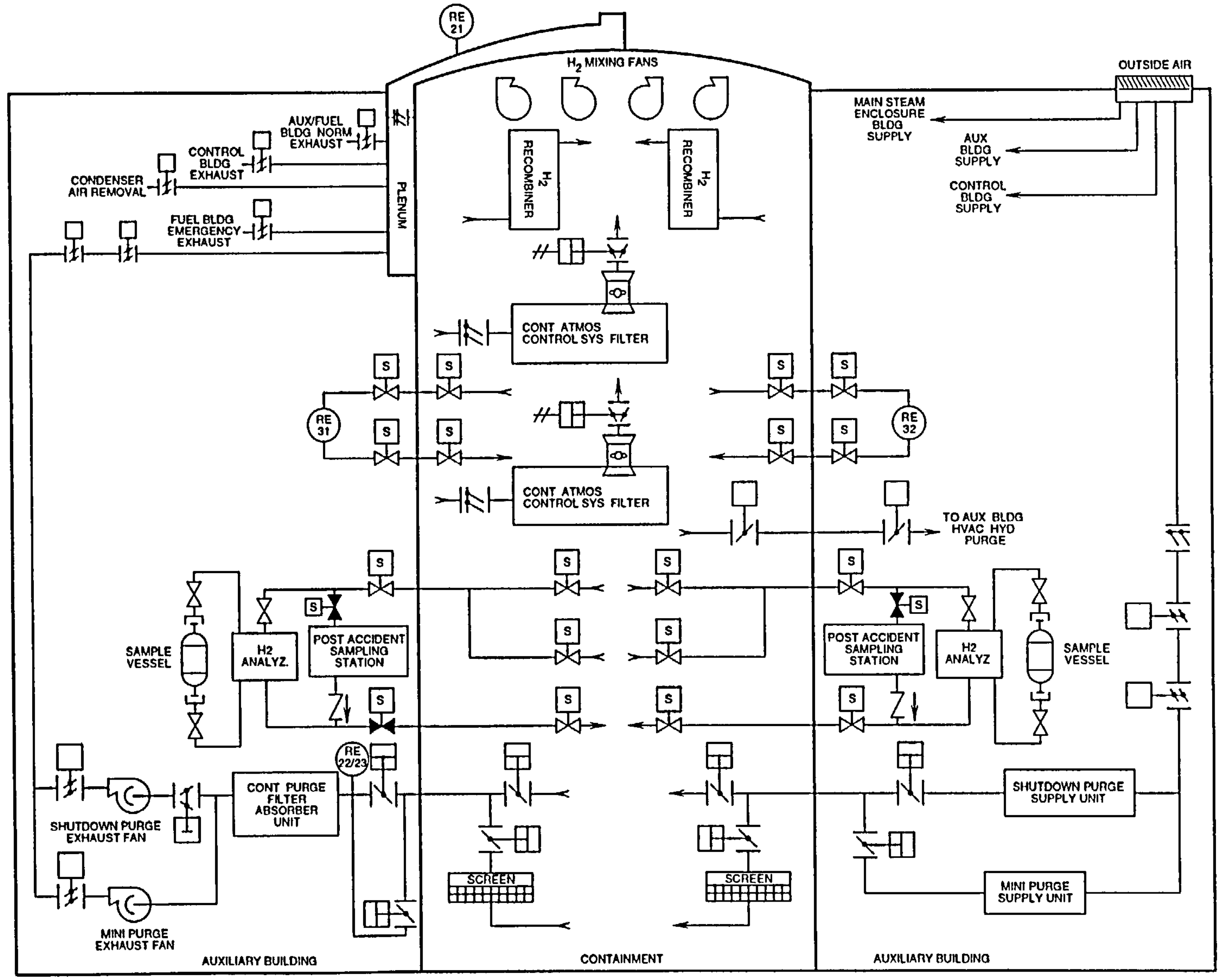

Figure 5.2-10 Containment Atmosphere Control System

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Section 5.3

Auxiliary Feedwater System

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5.3 AUXILIARY FEEDWATER SYSTEM

Learning Objectives:

1. State the purposes of the auxiliary feedwater system.
2. Describe the decay heat removal flowpath following a reactor trip under the following conditions:
   a. With off-site power available and
   b. Without off-site power available.
3. List the suction sources for the auxiliary feedwater pumps and under what conditions each suction source is used.
4. List three plant conditions that will result in an automatic start of the auxiliary feedwater system.

5.3.1 Introduction

The purposes of the auxiliary feedwater system are to:

1. Provide feedwater to the steam generators to maintain a heat sink for the following conditions:
   a. Loss of main feedwater,
   b. Unit trip and loss of off-site power, and
   c. Small break loss of coolant accident (LOCA).
2. Provide a source of feedwater during plant startup and shutdown.

5.3.2 System Description

The auxiliary feedwater (AFW) system (Figure 5.3-1) consists of two subsystems, one of which utilizes a single turbine-driven pump, and the other consisting of two electric motor driven pumps. Each of the two subsystems can deliver feedwater from the condensate storage tank (normal supply) or the service water header (backup supply) to all four steam generators. When the auxiliary feedwater system is started, it will deliver water to the steam generators to provide heat removal from the reactor coolant system. The steam dump control system (Chapter 11.2) will provide for steam release and heat removal from the steam generators.

In the event of a loss of off-site power, the reactor coolant pumps lose power and no longer supply forced circulation of coolant through the core. The auxiliary feedwater system is essential for core decay heat removal under these conditions. Since the condenser circulating water pumps also lose power, the condenser steam dumps are not available for steam release from the steam generators. The steam generator power operated relief valves (Chapter 7.1) are used to relieve the steam.

The auxiliary feedwater system is also essential in supporting core decay heat removal during a small break loss of coolant accident. During a small break loss of coolant accident, the injection flow rate from the emergency core cooling systems is not sufficient to provide adequate flow through the core for decay heat removal because of the reactor coolant system backpressure effect on emergency core cooling system flow and the slow reactor coolant system depressurization rate resulting the coolant discharge through the small break. Decay heat removal via the reactor coolant system and heat transfer to the steam generators is necessary for co᾿ᐧ cooling considerations under small break los ›f coolant accident conditions.

NOTE: During a large break loss of coolant accident, the emergency core cooling system flow alone is adequate to provide core cooling since the rapid reactor coolant system pressure reduction allows a much higher emergency core cooling system flow rate through the core (Chapter 5.1).

Since auxiliary feedwater is necessary to mitigate the consequences of an accident as discussed previously, the complete auxiliary feedwater system, with the exception of the suction supply from the condensate storage tank, has been designed to Seismic Category I specifications. In the event that the condensate storage tank is damaged or destroyed, the Seismic Category I service water system (Chapter 5.4) is available as a backup suction for the auxiliary feedwater pumps.

The auxiliary feedwater pumps will automatically start upon actuation of one of the following start signals:

1. Steam generator low-low level,
2. Loss of both main feedwater pumps,
3. Loss of one main feedwater pump with power above 80%,
4. An engineered safety features actuation signal, or
5. Loss of off-site power.

5.3.3 Component Description

5.3.3.1 Motor Driven Pumps

The auxiliary feedwater system is supplied with two motor driven pumps, each of which is powered from a different vital electrical distribution bus. The motor driven pumps are designed so that if only one pump is available, it can supply enough feedwater to two steam generators to cool the reactor coolant system to a point at which the residual heat removal system can be utilized for cooldown.

5.3.3.2 Turbine Driven Pump

The single turbine driven auxiliary feedwater pump has the sam discharge capacity as both motor driven pumps combined. The steam supply to drive the turbine driven pump is from the Seismic Category I portion of either of two main steam lines. The steam from the turbine is exhausted to the environment.

5.3.3.3 Level Control Valves

The level in the steam generators is controlled by means of level control valves. These valves are maintained in their full open position so that maximum auxiliary feedwater flow will be delivered to the steam generators when an actuation signal is received. These valves will be modulated by the operator to maintain the level in the steam generators.

5.3.3.4 Condensate Storage Tank

The condensate storage tank serves as the normal supply to the auxiliary feedwater pumps. A minimum amount of water is required by Technical Specifications to meet design considerations for cooldown. The hotwell level control system can affect the level in the condensate storage tank by either making up to the hotwell if the level in the hotwell is low or rejecting water to the condensate storage tank if the level in the hotwell is too high. If the required minimum level in the condensate storage tank is approached, an alarm is sounded in the main control room to prompt operator action before the limit is violated.

5.3.4 Operations

During plant startup, the auxiliary feedwater system supplies a controllable reduced feedwater flow rate necessary to maintain proper steam generator water level. The auxiliary feedwater system is able to supply adequate feed flow to maintain proper steam generator levels up to approximately two percent power, at which time the main feedwater system (Chapter 7.2) is started.

5.3.5 Summary

The auxiliary feedwater system is provided to ensure that an adequate amount of feedwater is supplied to the steam generators in the event of a loss of main feedwater, a unit trip coincident with a loss of off-site power, or a small break loss of coolant accident. This is necessary to maintain a proper heat sink to dissipate reactor decay heat. The auxiliary feedwater system will also be used during startups and shutdowns when the main feedwater system is not in service and when only a small amount of feedwater is required.

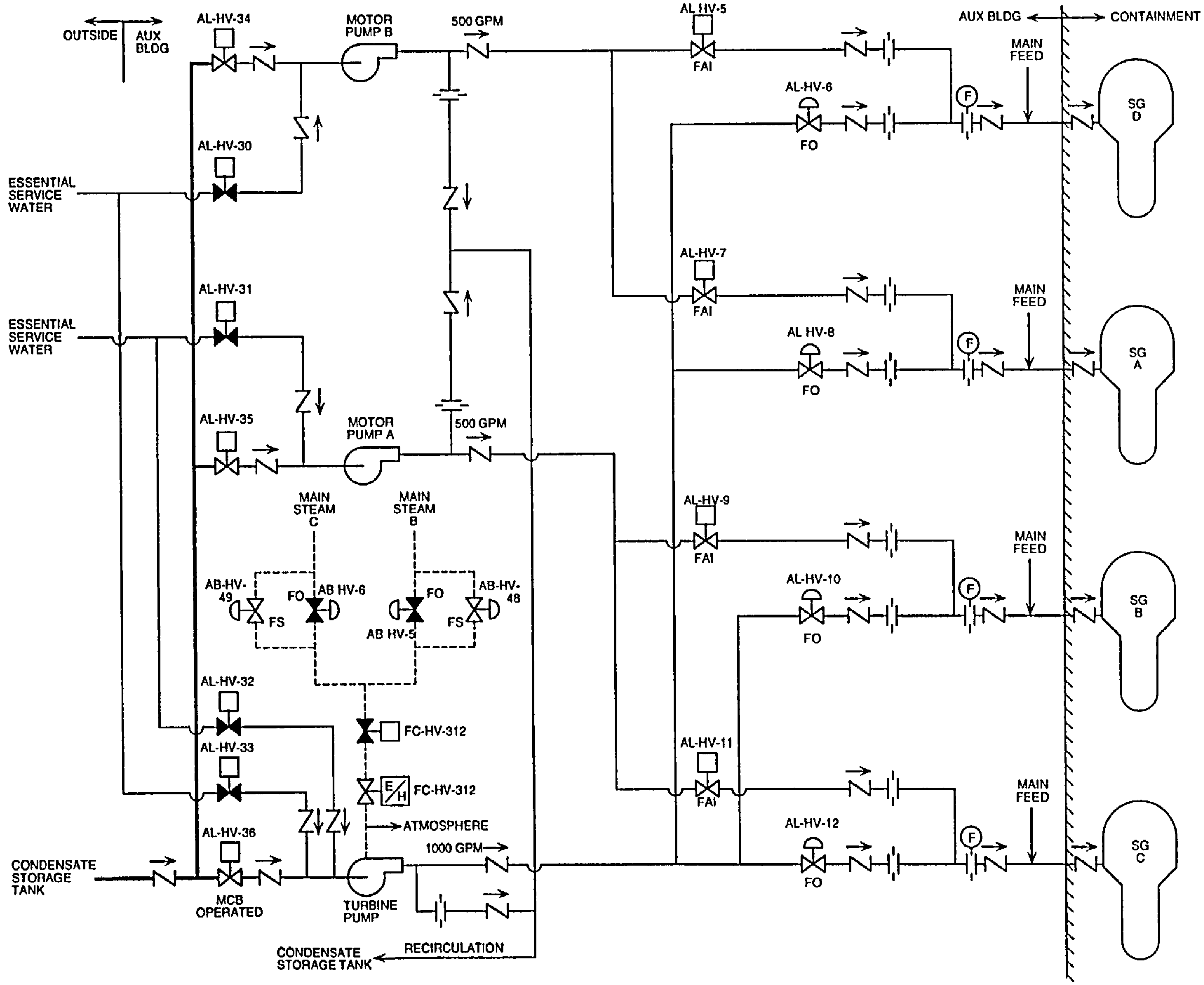

Figure 5.3-1 Auxiliary Feedwater System

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Section 5.4

Cooling Water Systems

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5.4 COOLING WATER SYSTEMS

Learning Objectives:

1. State the purpose of the component cooling water system.

2. List two component cooling water system loads.

3. Explain how the component cooling water system is designed to prevent the release of radioactivity to the environment.

4. State the purpose of the service water system.

5. List two service water system loads.

5.4.1 Component Cooling Water System

5.4.1.1 Introduction

The purposes of the component cooling water system are to:

1. Provide cooing for systems or components that contain radioactive fluids,

2. Provide cooling for engineered safety features systems and components, and

3. Provide a barrier between systems that contain radioactive fluids and the environment.

5.4.1.2 System Description

The component cooling water system (CCW) is a closed loop, low pressure system that transfers heat to the service water system from components that process potentially radioactive fluids. As such, it is a barrier between radioactive systems and the environment. It is operated at a lower pressure than the systems it removes heat from, and the service water system which cools it. Any leakage in the heat exchangers will leak into the component cooling water system. Leakage into the system will be detected by surge tank level, and if the leakage is from a radioactive system, it will be detected by radiation monitors in the pump suction line.

5.1.4.3 System Design and Operation

As shown in Figure 5.4-1, the component cooling water (CCW) system consists of three centrifugal pumps, three heat exchangers, a surge tank, and interconnecting piping. The CCW system is used during all phases of plant operation. It is a Seismic Category I system with a design pressure of 150 psig and a design temperature of 200°F. It is designed to meet single failure criteria. One pump and one heat exchanger are sufficient to meet design heat loads. The pumps and heat exchangers are physically and electrically separate with the C pump being powered from either train. An accident will start two pumps, one from each train. If the B pump is taken out of service, the C pump will be powered from a B train bus and valved into the system. There is a key-lock system to prevent the two operable pumps from being powered from the same train.

The surge tank provides suction for the pumps and allows for expansion, contraction, in-leakage, and makeup for out-leakage. The tank has a baffle to separate the two trains in order to meet passive failure requirements during the recirculation phase of a loss of coolant accident. Level detectors on the tank will alarm on high or low level. The tank is vented to the auxiliary building atmosphere. High radiation in the pump suction lines will automatically close the vent.

The component cooling water system supplies cooling water to the following components:

1. Residual heat removal heat exchangers,
2. Residual heat removal pumps,
3. Safety injection pumps,
4. Charging pumps,
5. Reactor coolant pump motors and thermal barriers,
6. Letdown heat exchanger,
7. Excess letdown heat exchanger,
8. Seal water heat exchanger,
9. Spent fuel pit heat exchanger,
10. Sample heat exchangers,
11. Reactor vessel support cooling,
12. Boric acid evaporator condensers,
13. Waste gas compressors, and
14. High temperature containment penetrations.

Non-vital loads will be isolated on an engineered safety features actuation signal. The excess letdown heat exchanger is isolated on a phase A containment isolation signal and reactor coolant pumps on a phase B containment isolation signal.

5.4.2 Service Water System

5.4.2.1 Introduction

The purpose of the service water system is to provide the heat sink for all non-radioactive plant equipment *except* the main condenser.

5.4.2.2 System Design and Operation

The service water system is the ultimate heat sink for all vital equipment. It is used during all phases of plant operation. The three centrifugal pumps take suction on the lake, river, ocean, or cooling tower, discharge through the various systems and components, and then returns to the environment (Figure 5.4-2).

The service water system is designed to be Seismic Category I and meets single failure criteria. The service water system is divided into two trains, which are physically and electrically independent. The A and B pumps are powered from the A and B buses, respectively, while the C pump can be powered from either bus, depending on the system lineup. During normal operations, one or two pumps will be used, depending on plant loads. An engineered safety features actuation signal will start all three pumps. One pump and associated piping will handle the heat loads during an accident.

The following components are supplied by the service water system:

1. Component cooling water heat exchangers,
2. Containment fan coolers,
3. Diesel generator coolers,
4. Control room air conditioning condensers,
5. Auxiliary building ventilation cooling coils, and
6. Auxiliary feedwater pumps emergency supply.

5.4.3 Circulating Water System

5.4.3.1 Introduction

The purpose of the condenser circulating water system is to provide cooling water to the main condenser tubes and acts as a heat sink for the turbine and steam dump systems.

5.4.3.2 System Design and Operation

The three circulating water pumps (per unit) are powered from non-essential electrical buses and take suction from the intake forebay through travelling screens. The travelling screens filter out any small trash which might clog condenser tubes. Two pumps are normally required at full load, but all three may be used in warm weather or to meet environmental Technical Specification requirements on condenser differential temperature.

The three circulating water pumps discharge into a common header to supply the main condenser (Figure 5.4-3). The cooling water circulates through the tubes of the main condenser and then out through the outlet structure. In cold climates, part of the condenser outlet flow may be diverted back to the inlet for ice melting in the inlet structure or forebay.

Planned releases from the liquid radioactive waste system are mixed with the discharge water from both the service water and circulating water systems to ensure proper dilution before reaching the environment.

Controls, interlocks, and instrumentation are provided in the main control room to enable the plant operator to modulate the various system valves and vary the number of pumps in service.

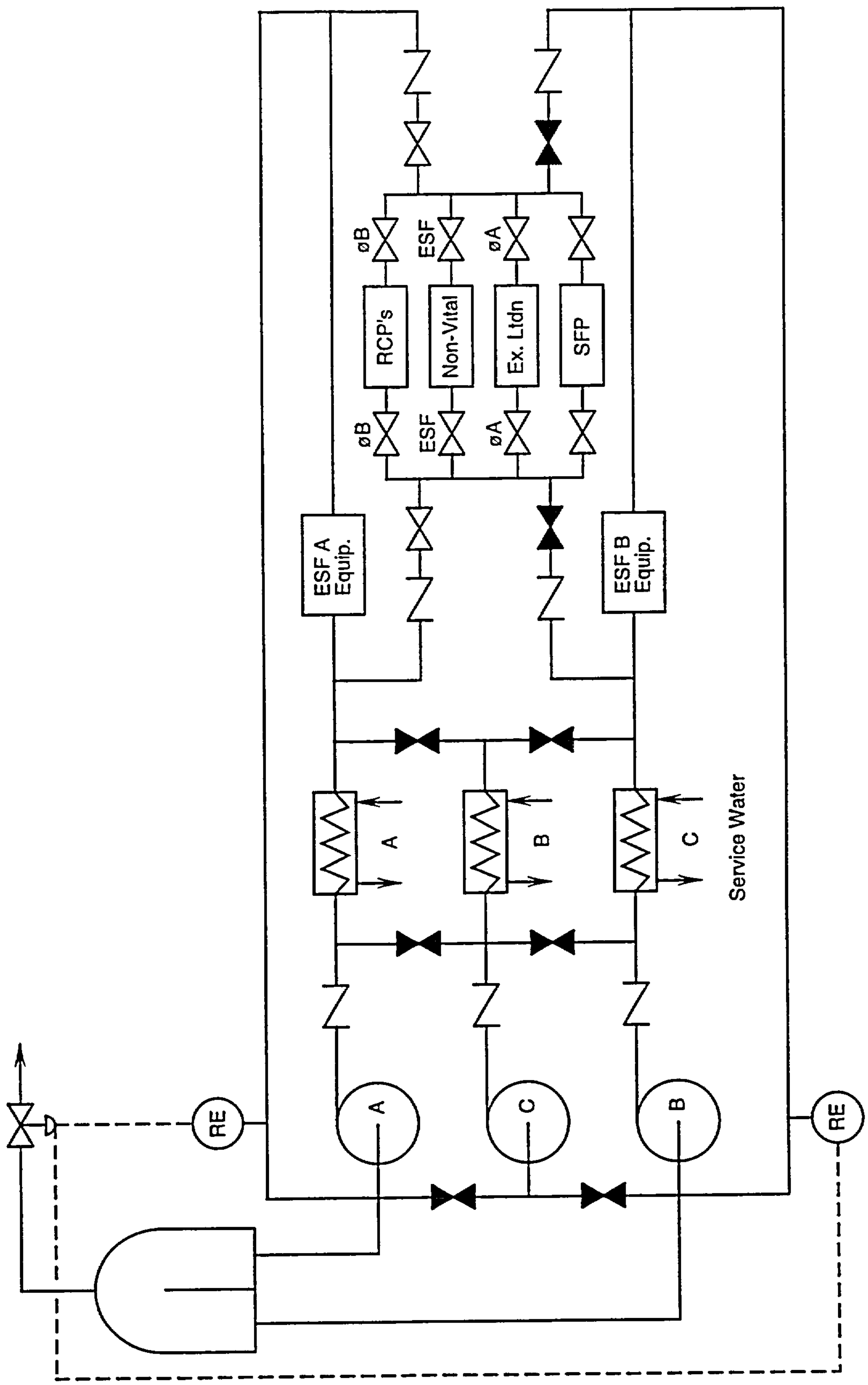

Figure 5.4-1 Component Cooling Water System

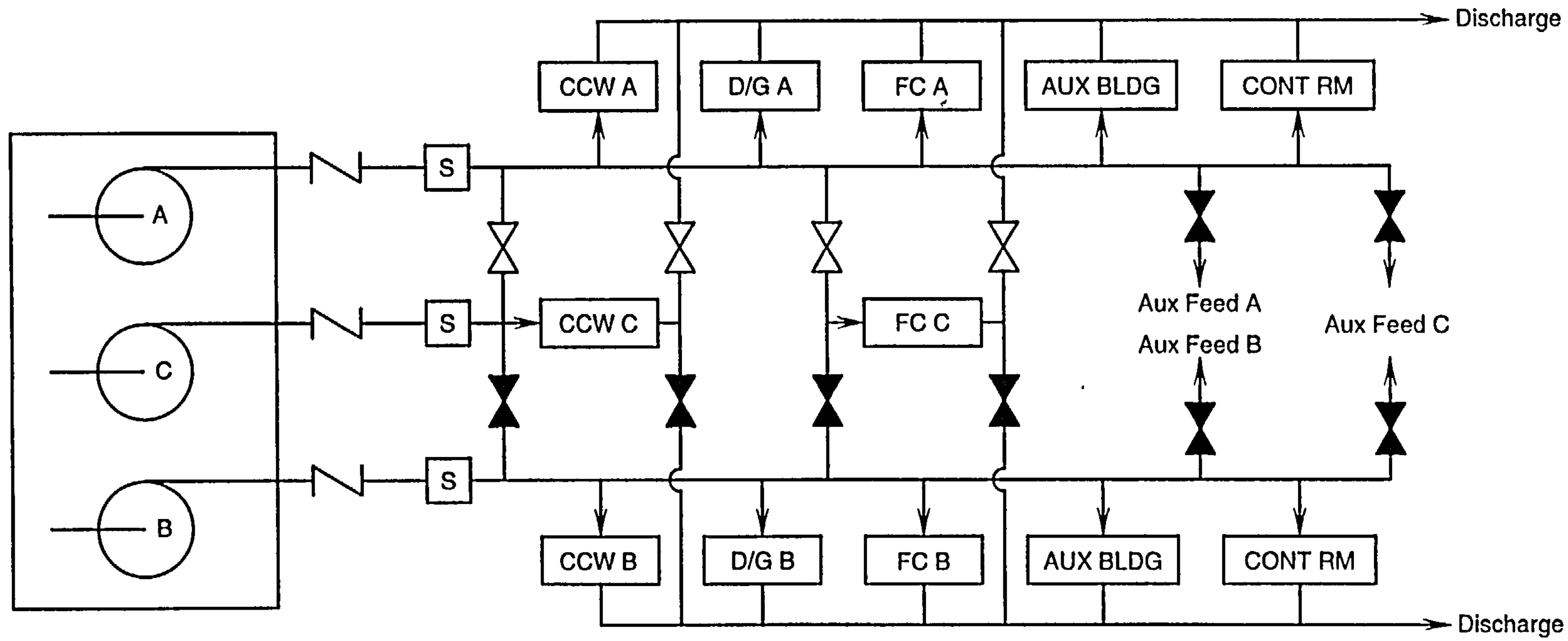

Figure 5.4-2 Service Water System

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GATE POSITION TABLE			
COMPONENT	MODES		
	OPEN	HELPER	CLOSED
#1 GATE	CLOSED	OPEN	CLOSED
#2 GATE	CLOSED	CLOSED	OPEN
DIFFUSER GATE	OPEN	OPEN	CLOSED
LIFT PUMPS	OFF	ON	ON
BYPASS GATE	OPEN	THROTTLED	CLOSED

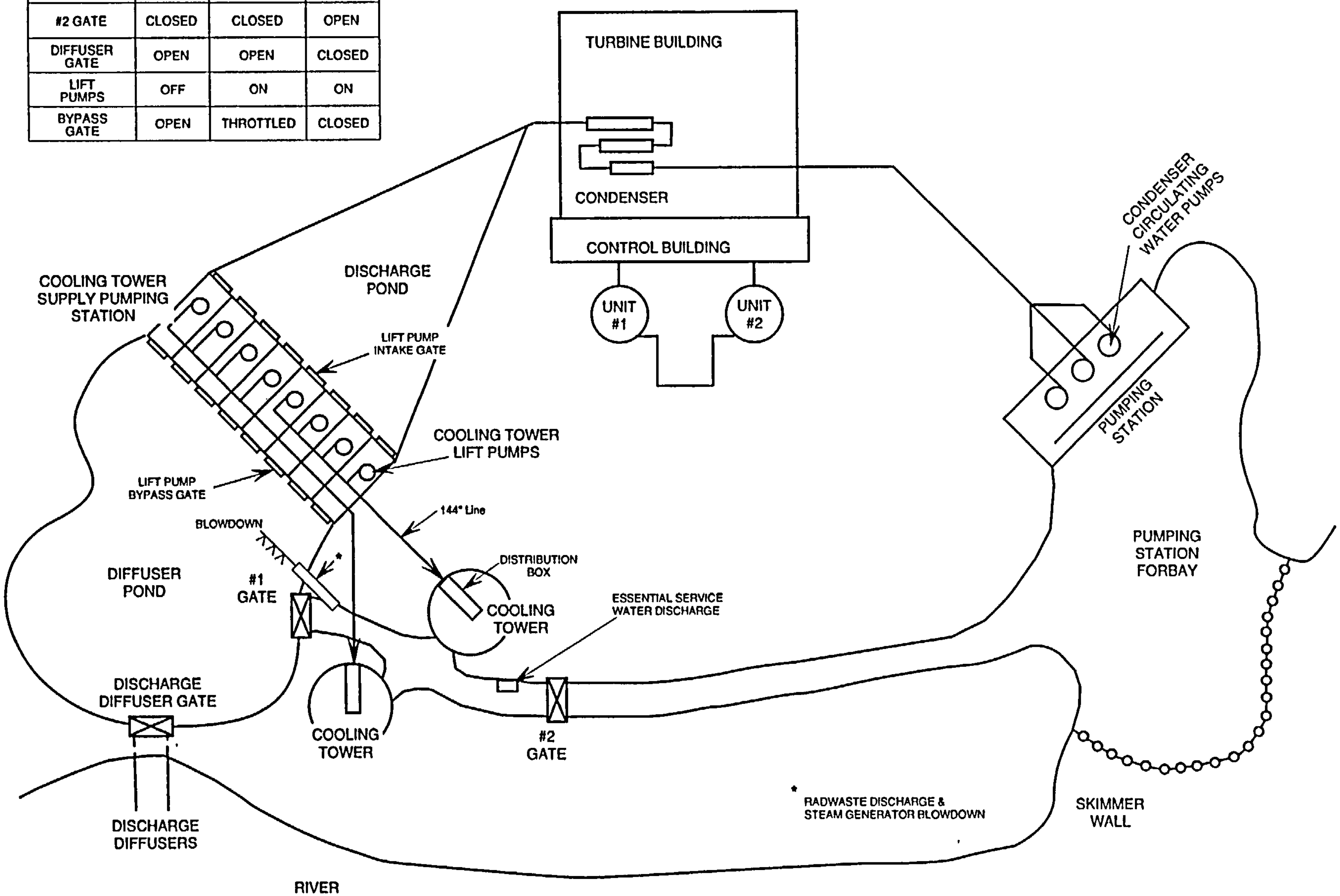

Figure 5.4-3 Condenser Circulating Water System

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Chapter 6.0

Electrical Distribution System

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6.0 ELECTRICAL SYSTEMS

Learning Objectives:

1. List the purposes of the plant electrical systems.

2. Explain how the plant electrical system is designed to ensure reliable operation of equipment important to safety with emphasis on the following:

   a. Redundancy,
   b. Separation (physical and electrical),
   c. Reliable control power,
   d. Reliable instrumentation power, and
   e. Reliable AC power.

3. List the normal and emergency power sources to the vital (Class 1E) AC electrical distribution system.

4. State the purpose of the diesel generators.

5. List the automatic start signals for the diesel generators and the condition that causes the closure of the diesel generator output breaker.

6. Describe the automatic actions that occur in the electrical system following a plant trip and loss of off-site power.

7. List four (4) typical loads powered by the vital 4160 volt buses.

6.1 Introduction

The purposes of the plant electrical system are to:

1. Provide a reliable source of electrical power to systems important to safety,

2. Provide a connection to the off-site distribution system (grid), and

3. Provide a source of power to systems for normal plant operation (non-safety systems).

6.2 System Description

The electrical systems are designed to provide a diversity of reliable power sources to unit components and equipment in addition to supplying power to the utility's transmission network. The on-site electrical systems are referred to as "auxiliary" electrical systems. The station auxiliary power is normally supplied by the main generator by way of unit auxiliary transformers. If the main generator is unavailable or tripped, station auxiliary power is supplied from the utility's transmission network via the system auxiliary transformers. In the event of a total loss of auxiliary power from off-site sources, power required for safe shutdown and/or accident response is supplied from diesel generators located on-site.

The ability to function in the event of a single failure and separation of redundant equipment are designed into the electrical power system.

The station auxiliary electrical system is designed to ensure electrical isolation and physical separation of the redundant power supplies for station equipment required for safety. Due to the limitations imposed on the amount of power which the diesel generators can deliver, the auxiliary power system is separated into vital (Class 1E) equipment buses which can be supplied by the diesels, and non-vital equipment buses, which are not required for safe shutdown or accident response, and are not supplied by the diesels on a loss of off-site power.

The vital (Class 1E) equipment buses are designed to provide two power trains with physical separation and the capability of electrical separation. Each train can be powered by its own diesel generator upon loss of normal power. This train separation and backup power supply (diesel generator) ensures that a single failure in the auxiliary power system will not compromise safe shutdown or accident response capability. Batteries are provided as a source of power for vital instrumentation, control power, emergency lighting, etc. They are maintained fully charged by battery chargers which receive power from the vital AC buses.

6.3 Component Description

6.3.1 500 KV Network Transmission

Electrical energy generated at the station is stepped up to 500 KV (thousand volts) by the main transformer and fed into the 500 KV switchyard. The power is transmitted off-site to the utility's network by several separate high voltage power lines. The 500 KV switchyard is normally split between Unit #1 and Unit #2 with each feeding two separate distribution stations.

6.3.2 Main Generator and Transformer

The prime mover of the generator is the steam driven main turbine. The rotating armature (rotor) is cooled by hydrogen, and the stationary conductors (stator) are cooled by demineralized water. The main transformer consists of two half-size transformers. Each half-size transformer is three-phase and rated at 22/500 KV.

6.3.3 Auxiliary Power System

The auxiliary power system provides a reliable source of power to all plant auxiliaries required during any normal or emergencv mode of plant operation.

The design of the system is such that sufficient independence or isolation between the various sources of electrical power is provided to guard against concurrent loss of all auxiliary power.

The auxiliary electrical system is designed to provide a simple arrangement of buses, requiring a minimum of switching to restore power to a bus in the event that the normal supply to it is lost.

The basic arrangement of the plant electrical system is shown in Figure 6-1.

Power to the auxiliary electrical system is normally provided by the main generator by way of the two unit auxiliary transformers to the two 4160 volt AC non-vital buses. If the normal source of power is lost, a fast transfer occurs which opens the breaker from the unit auxiliary transformer and closes the breaker from the system auxiliary transformer. The fast transfer occurs very rapidly (within five cycles) to prevent the loss of major equipment, specifically the reactor coolant pumps. Power to the auxiliary electrical system is now supplied from an off-site source to the non-vital 4160 volt AC buses and from there to the rest of the auxiliary electrical system. Normal switch over from off-site to on-site supply occurs at approximately 15% power.

6.3.4 Non-Vital Buses

The 4160 volt AC and 480 volt AC plant auxiliary equipment which is non-vital to safe shutdown and have large power requirements will be supplied from the 4160 volt AC non-vital buses. Reactor coolant pumps, condenser circulating water pumps, condensate pumps, etc. are in this category. The equipment is divided between the two buses to provide diversity.

Two 480 volt AC non-vital buses are supplied from the 4160 volt non-vital buses via the 4160/480 volt AC transformers. Smaller non-vital loads such as motor control centers, small pumps, and non-essential lighting are fed from these buses.

6.3.5 Vital 4160 Volt AC Buses

The two 4160 volt vital buses normally receive power from the 4160 volt non-vital buses. If this source of power is lost, the diesels will automatically start and tie in to the 4160 volt vital buses while the breakers from the non-vital buses open. This prevents non-vital equipment from overloading the diesels during a loss of off-site power. The "1A" 4160 volt vital bus feeds all of the equipment of engineered safety features train "A," while bus "1B" supplies the train "B" equipment. Included as loads on the 4160 volt AC vital buses are the residual heat removal pumps, safety injection pumps, centrifugal charging pumps, component cooling water pumps, service water pumps, and the auxiliary feedwater pumps.

6.3.6 Vital 480 Volt AC Buses

Four vital 480 volt AC buses supply the smaller vital loads, such as essential lighting, battery chargers, pressurizer heaters, and ventilation and cooling fans. Power to the 480 volt AC vital buses is received from the two 4160/480 volt transformers.

6.3.7 125 Volt DC Buses

The four 125 volt DC buses are each supplied by a battery and a battery charger. The battery charger is sized to carry all loads on the DC bus and to keep the battery fully charged. The battery charger receives its power from the 480 volt AC vital bus. Loads such as emergency lighting, computer inverter, electrical distribution breaker controls, and control power are fed from the 125 volt DC buses. Some designs may incorporate a manually operated cross-tie breaker between the "A" train and "B" train DC buses. This cross-tie is provided for plant flexibility such as performing maintenance on various equipment that would normally supply the affected DC bus. If the battery charger is lost, the batteries are designed to provide power to the DC buses for a specified time period.

6.3.8 120 Volt AC Vital Instrumentation Buses

Four buses supply power for reactor protection (four protection channels, 1 bus assigned to each channel) and for the engineered safety features instrumentation and control. The relative importance of these buses is apparent in the number and diversity of the power supplies to these buses. Normal power comes from an inverter/auctioneer. This device compares its two inputs and selects the higher voltage to be passed on to the 120 volt AC vital instrument bus. One input is from the 125 volt DC control bus. The other is form the 480 volt AC vital bus via a 480/120 volt transformer. This 120 volt AC supply is rectified to 125 volt DC, then delivered to the auctioneer. The auctioneer selects the higher of the two inputs, inverts it to 120 volt AC, and delivers it to the 120 volt AC bus. Since these two sources are in turn supplied by highly reliable sources (diesel, battery), a very dependable power supply is assured. In addition to the inverter/auctioneer, each 120 volt AC vital instrument bus can also receive power from the 480 volt AC vital bus. This is supplied via a 480/120 volt AC transformer and a normally open, manually operated breaker.

6.3.9 Diesel Generator

If both sources of normal auxiliary power are lost (unit auxiliary transformer and system auxiliary transformer), the equipment essential to safe shutdown will be supplied by the Seismic Class I diesel generators. These diesels will automatically start and tie onto the 4160 volt AC vital buses on a loss of voltage on the bus. Each diesel is designed to reach rated speed and be ready to accept load within ten seconds, and accept full load within thirty seconds after receiving a start signal. The unit will start on an engineered safety features actuation signal or a loss of power on its associated vital bus. The generator tie breaker to the bus will not close unless the bus is deenergized.

To prevent overloading and tripping the diesel, the major loads are automatically stripped off the bus before the diesel generator output breaker closes. The loads will then be sequenced back on onto the bus one at a time. The entire sequence takes about 30 seconds and is accomplished by an automatic sequencer. The sequencer also prevents overloading by loading only the equipment considered vital to a safe shutdown.

6.4 Summary

The electrical power system is perhaps the most important engineered safety feature installed in the nuclear power unit. A major purpose of the system is to supply a reliable source of power, under all conditions, to systems that are required for plant safety. Examples of safety systems and components are: (1) engineered safety features valves and pump motors, (2) control power for engineered safety features equipment, and (3) instrumentation required to monitor plant status during normal and abnormal events. In addition to its safety purpose, the electrical power system supplies energy to auxiliary systems that are required for the generation of electricity and provides the necessary connections for the transmission of generated power to the consumer.

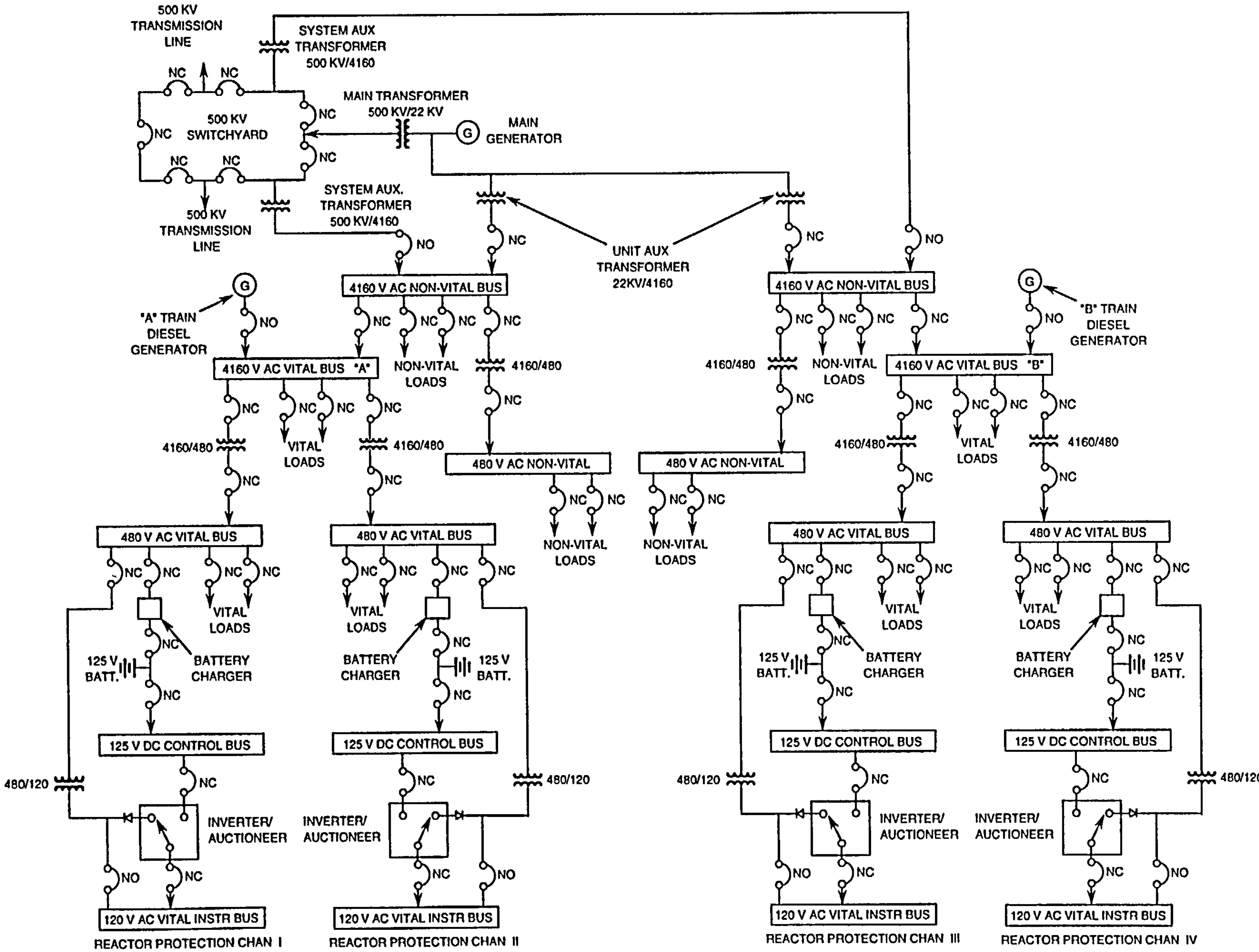

Figure 6-1 Typical Power Station Electrical Diagram

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Section 7.1

Main and Auxiliary Steam Systems

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7.1 MAIN AND AUXILIARY STEAM SYSTEMS

Learning Objectives:

1. State the purposes of the main steam system.
2. Identify the portion of the main steam system that is Seismic Category I.
3. List in the proper flow path order and state the purpose of the components and connections located in the Seismic Category I portion of the main steam system:
   a. Steam generator,
   b. Flow restrictor,
   c. Power operated relief valve (PORV),
   d. Code safety valves,
   e. Steam supply to auxiliary feedwater pump turbine,
   f. Main steam isolation valves (MSIV), and
   g. Main steam check valves.
4. List in the proper flow path order and state the purpose of the following components associated with the main steam system:
   a. Turbine throttle/governor valves,
   b. High pressure turbine (HPT),
   c. Moisture separator reheater (MSR),
   d. Turbine intercept/reheat stop valves,
   e. Low pressure turbine (LPT), and
   f. Condenser.

7.1.1 Introduction

The purposes of the main steam system are to:

1. Transfer steam from the steam generators to the turbine generator and auxiliary steam systems,
2. Provide overpressure protection for the steam generators, and
3. Provide a path for decay heat removal.

The steam and power conversion system includes the main steam system and the turbine generator and is designed to convert reactor heat into useful electrical energy. The steam generators transfer heat from the reactor coolant (primary) to the main steam system (secondary) and act as a barrier between the radioactive primary coolant and the non-radioactive steam system. The main steam system transfer the steam from the steam generators to the main turbine where the thermal energy of the steam is converted to electrical energy. Auxiliary uses for main steam include steam dump, reheat steam, feedwater pump turbines, air ejector operating steam, etc. For an 1100 MWe plant, required steam flow will be on the order of fourteen million pounds per hour.

7.1.2 Main Steam

7.1.2.1 System Description

Dry, saturated steam exits the steam generators (Figure 7.1-1) through individual main steam lines which are routed from the steam generators to the feedwater-steam pipe tunnels. Steam line diameters are chosen to limit the pressure difference between steam generators to a maximum of ten psid, which maintains system balance and ensures uniform heat removal from the reactor coolant system.

The main steam system consists of more than 2000 feet of large diameter piping. The four main steam headers, one for each steam generator, are typically from 28 to 32 inches in diameter. The containment penetration for each header provides a fixed anchor for the piping system. The piping up to and including the main steam check valves constitutes the Seismic Category I portion of the main steam system. The only penetration into the main steam piping inside of containment is for the steam flow detectors for each steam generator. The functions of this instrument are covered in the chapter covering the steam generator water level control system (Chapter 11.1).

Four pressure detectors are located just outside of containment on each steam header. Three of the detectors are used for protection, steam generator level control, and indication as discussed in Chapter 11.1. The fourth detector is used exclusively for the control of a power operated relief valve (PORV). A single PORV is installed on each main steam line.

7.1.2.2 Flow Restrictor

At the exit of each steam generator, a flow restrictor (Figure 7.1-3) is installed to limit the maximum steam flow (therefore the maximum reactor coolant system cooldown rate) during a steam line break between the restrictor and the main steam isolation valve (MSIV). On later designs, this restrictor is incorporated into the outlet nozzle of the steam generator. In both designs, the differential pressure developed across this restrictor is processed to indicate steam flow and used in the reactor protection system to detect a main steam line break (Chapter 12) and in the steam generator water level control system (Chapter 11.1).

7.1.2.3 Safety and Relief Valves

Overpressure protection for the main steam system is provided by safety and relief valves. Each steam line is furnished with a power operated relief valve (PORV) and five code safety valves, which all discharge directly to atmosphere. The PORV receives an operating signal from one of the steam line pressure detectors and is an air operated modulating valve. The PORVs are designed to prevent steam generator pressure from reaching the safety valve setpoint during transients and to dissipate reactor decay heat to the atmosphere is the normal heat sink (main condenser) is not available. Since the PORVs provide a means of dissipating decay heat during an emergency, some are provided with a backup electric motor operator in the event of a loss of control air. Each PORV has a maximum capacity of 10% of rated steam generator flow.

The code safety valves are spring-loaded, self-actuating valves and have a combined capacity of 105% of rated steam flow at 110% of the steam generator design pressure. This is in accordance with the American Society of Mechanical Engineers (ASME) boiler and pressure vessel code. The operability of code safety valves is a Technical Specification requirement to ensure overpressure protection of the main steam system for plant operation.

7.1.2.4 Main Steam Isolation Valves

Main steam line isolation is accomplished by closing a hydraulically operated globe valve in each steam line just outside the containment. These main steam isolation valves (MSIVs) close automatically on high steam flow coincident with either low-low T_{avg} or low steam line pressure (indicative of a steam break), or on a high-high containment pressure condition (Chapter 12, Reactor Protection System). The MSIVs can be manually operated from the main control board or local panels.

The main steam line swing check valves, located just downstream of each MSIV, protect against back flow of steam from other steam generators in the event of a steam line break inside the containment. All piping and components up to the check valves, including the valves and their enclosing structure, are Seismic Category I. The Seismic Category I portions of the main steam and feedwater lines are missile protected and are provided with restraints to preclude additional line failures due to pipe whip in the event of a main steam or feedwater line break.

7.1.2.5 Turbine Driven Auxiliary Feedwater Pump

Main steam from two of the steam generators, upstream of the MSIVs, is used to supply steam to the turbine-driven auxiliary feedwater pump. The motor-driven and turbine-driven auxiliary feedwater pumps are used to supply feedwater to the steam generators when normal feedwater is unavailable (Chapter 5.3). Operation of the turbine driven auxiliary feedwater pump is very important to ensure adequate steam generator water inventory to allow reactor decay heat removal if all AC power is lost (i.e., no power to the motor-driven auxiliary feedwater pumps). These steam supply lines and the auxiliary feedwater pump turbine are safety systems designed to Seismic Category I specifications.

7.1.2.6 Main Turbine

The main steam system transfers high pressure saturated steam to the main turbine, where the energy of the steam is extracted to turn the turbine rotor and attached electrical generator. The entry of steam into the high pressure turbine is controlled by the fully open throttle valves and the modulated governor valves. The position of the valves is controlled by the turbine electrohydraulic control (EHC) system (Chapter 7.3). First stage high pressure turbine impulse pressure (P_{imp}) is detected by a pressure transmitter, and the signal is used in protection and control systems as an indication of turbine power.

The exhaust steam from the high pressure turbine (Figure 7.1-2) is directed through the moisture separator reheater (MSR), where moisture is removed from the steam, and the steam is superheated. The dry, superheated steam is then directed through the intercept and reheat stop valves and into the three low pressure turbines. All high and low pressure turbine steam admission valves close on a turbine trip signal to isolate the main turbine from the main steam system.

The low energy steam from the low pressure turbines is exhausted to the condenser, where it is condensed as it gives up its heat of condensation to the plant circulating water system (Chapter 5.4). The condensate is pumped through a series of feedwater heaters (Chapter 7.2) and returned to the steam generators to begin the cycle again.

7.1.2.7 Steam Dump Valves (Turbine Bypass Valves)

The steam dump system (Chapter 11.2) is provided to accommodate the inertial heat from the primary cycle. Inertial heat is present during a turbine load rejection because the reactor power cannot be reduced as fast as turbine power. To dissipate this extra reactor heat, an alternate load is provided by the steam dump system. During a load rejection greater than the capacity of the reactor control system, or after a turbine trip, the steam dump valves open to dump steam from the steam generators to the condenser (Figure 7.1-1). There are twelve steam dump valves which operate sequentially to distribute the steam evenly throughout the condensers. One group commonly called the "cooldown" valves are used for a normal controlled cooldown of the primary system by manually adjusting the dump valves positions to dissipate more than the total of decay heat and reactor coolant pump heat.

Steam dump systems may be provided to allow up to a full load rejection without a reactor trip. Most designs, however, are sized for forty percent rejection capability.

7.1.2.8 Main Steam (Auxiliary)

The four main steam lines tie into a common header in the turbine building. The common main steam header (sometimes called the "mixing bottle") supplies the main feed pump turbines, moisture separator-reheaters, feedwater heaters, gland steam, and the auxiliary steam system.

Turbine gland sealing steam is used to seal the high and low pressure turbine rotor/casing glands to prevent either steam outleakage or air inleakage along the turbine shaft. Excessive air inleakage can cause a loss of condenser vacuum with resultant turbine inefficiency or even a plant trip.

Main feedwater pump turbine steam supply, on plants equipped with turbine-driven main feedwater pumps, is from two steam sources. The startup source is from the main steam line. As the main turbine is loaded, the steam pressure from the moisture separator reheaters (MSRs) begins to increase. When this pressure is sufficiently high, the main feedwater pump turbine control valves will automatically shift to a running supply of steam from the MSR reheat steam outlet to the low pressure turbines. This arrangement is necessary because at low loads, the steam pressure from the MSRs is too low to drive the feed pumps. Using reheat steam from the MSR for feed pump supply is more efficient than using high pressure steam from the main steam system.

7.1.3 Auxiliary Steam

The auxiliary steam system supplies low pressure steam that is required to operate various equipment and systems that directly or indirectly support plant operations and power generation. The auxiliary steam system provides steam to the following loads:

- Plant heating,
- Storage tank heating,
    - Refueling water storage tank,
    - Reactor makeup water storage tank,
    - Condensate water storage tank, and
    - Demineralized water storage tank.
- Boric acid batching tank,
- Boron recycle evaporator,
- Liquid radwaste evaporator,
- Secondary liquid evaporator,
- Turbine steam seal system,
- Main condenser sparging,
- Decontamination stations,
- Domestic hot water, and
- Moisture separator reheater tube blanketing.

The auxiliary steam system is supported by an oil-fired boiler that is placed in service when the reactor is to be shut down.

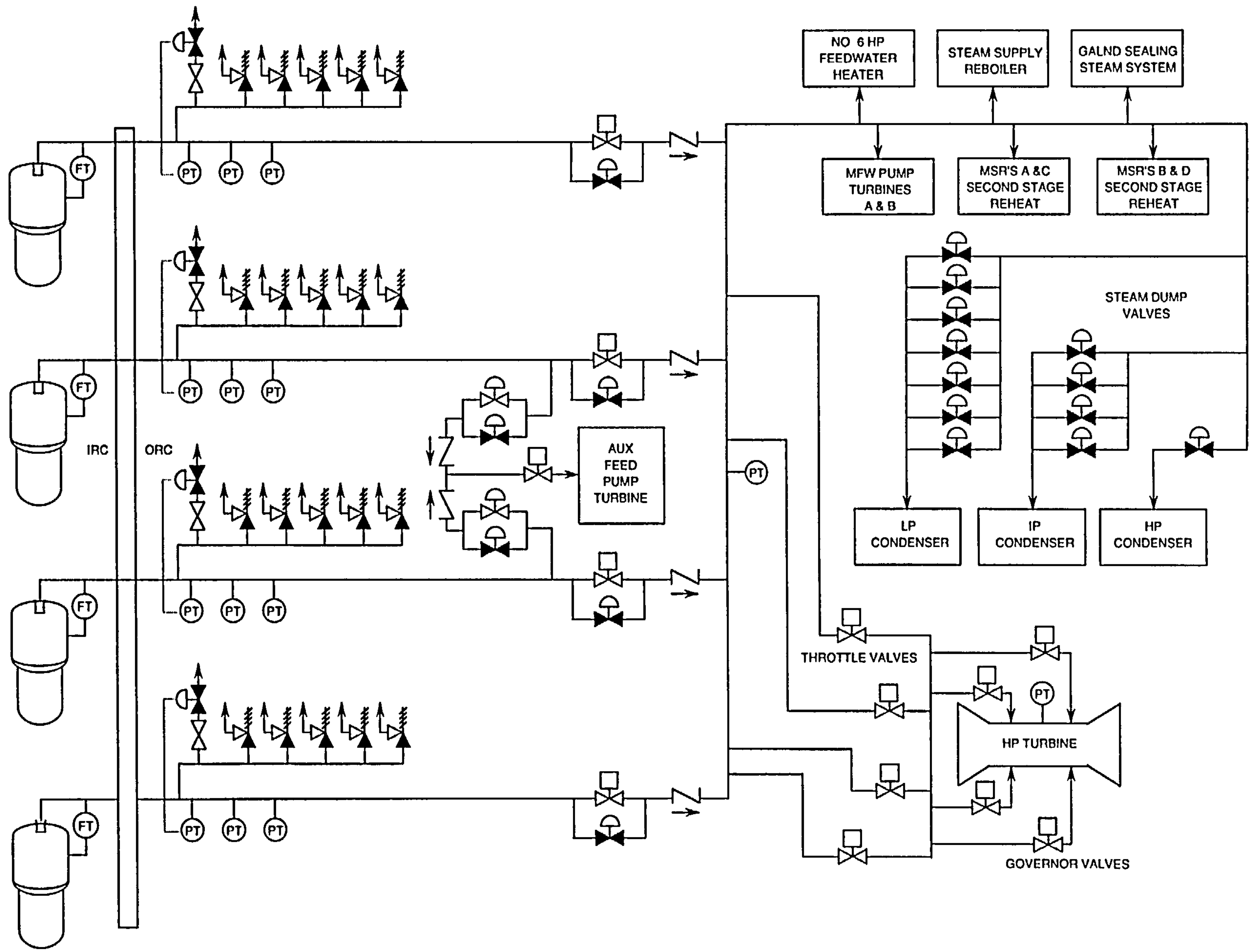

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Figure 7.1-1 Main Steam System-High Pressure

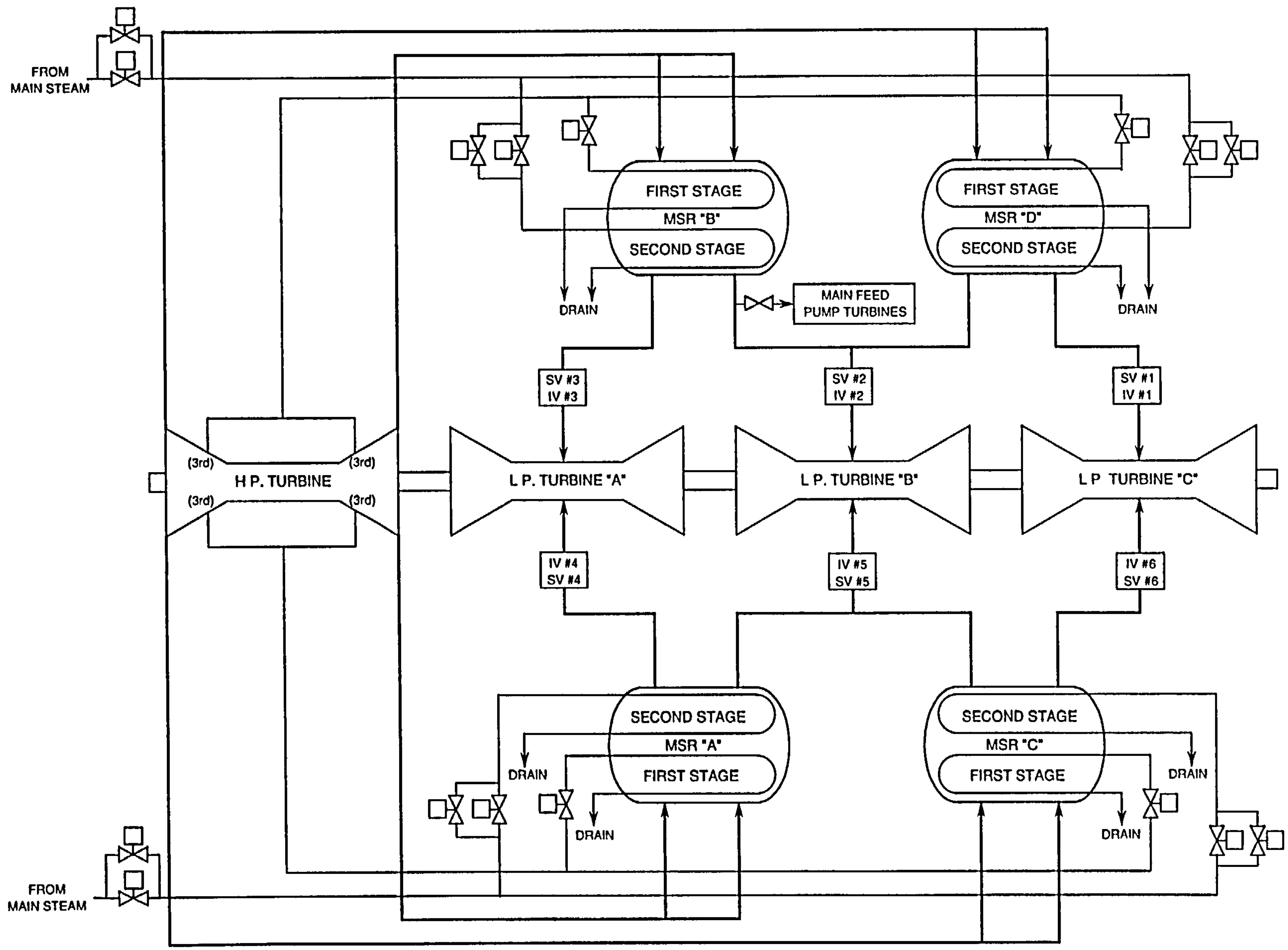

Figure 7.1-2 Main Steam System - Low Pressure

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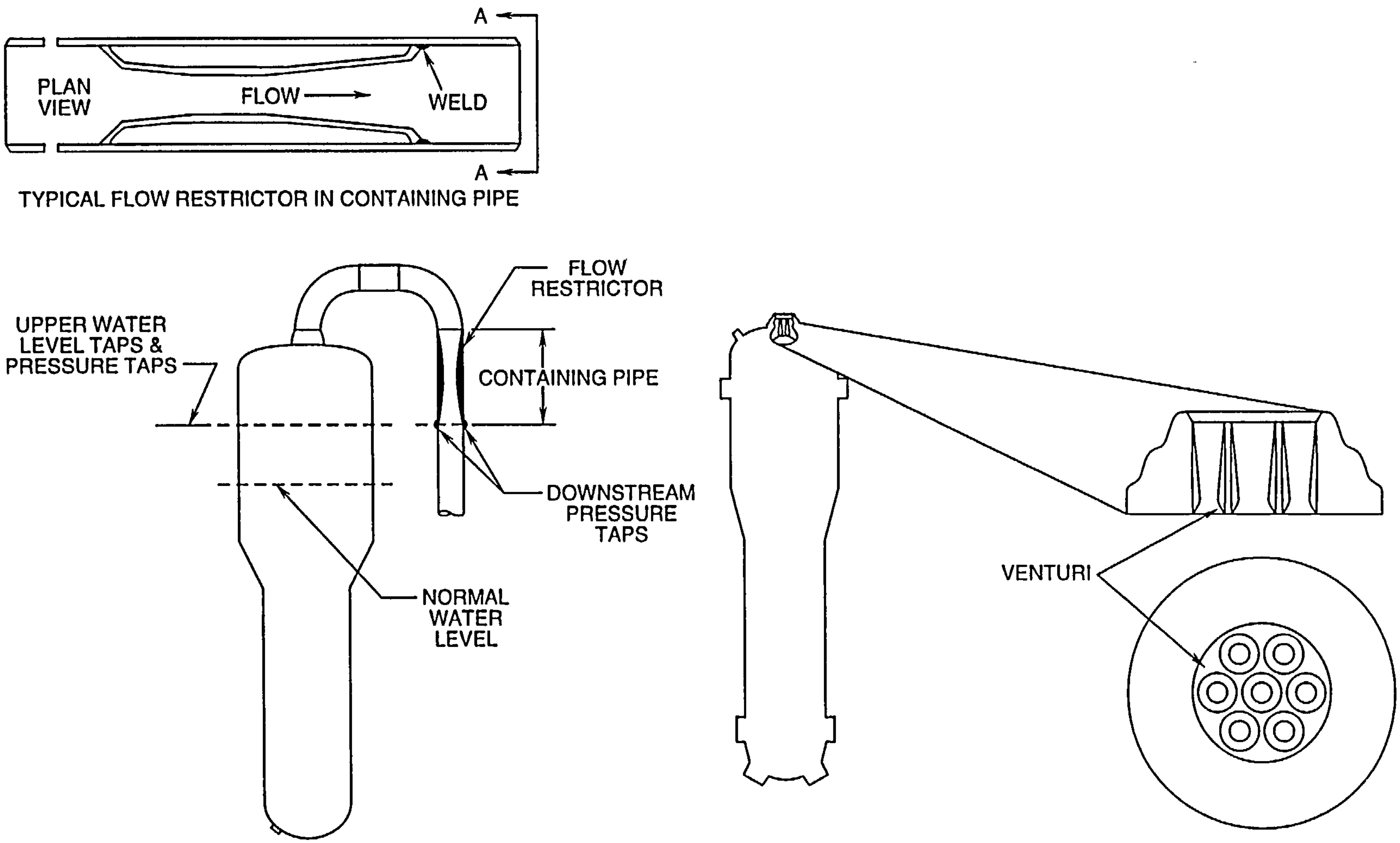

Figure 7.1-3 Flow Restrictor (Two Types)

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Section 7.2

Condensate and Feedwater System

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7.2 CONDENSATE AND FEEDWATER SYSTEM

Learning Objectives:

1. List the purposes of the condensate and feedwater system.

2. State the purpose of the components and penetrations in the Seismic Category I portion of the main feedwater system:

   a. Main feedwater isolation valves (MFIV),
   b. Auxiliary feedwater (AFW) system penetrations, and
   c. Main feedwater check valves.

3. List in the proper flow path order and state the purpose of the following condensate and feedwater system components:

   a. Main condenser,
   b. Hotwell,
   c. Condensate (or hotwell) pumps,
   d. Condensate demineralizer (polishers),
   e. Low pressure feedwater heaters,
   f. Main feedwater pumps (MFP),
   g. High pressure feedwater heaters,
   h. Feedwater control and bypass valves, and
   i. Steam generators (SG).

4. State the sources of heat for the low pressure and high pressure feedwater heaters.

7.2.1 Introduction

The purposes of the condensate and feedwater system are to:

1. Transfer and preheat water from the main condenser to the steam generators,

2. Collect and distribute heater drains, and

3. Provide for purification and secondary chemistry control.

The main condenser accepts the exhaust steam from the low pressure turbines (Figure 7.2-1). The steam is condensed and deaerated. The condensate then drains into the hotwells (located at the bottom of the condenser) and combines with the condensate draining from the low pressure feedwater heaters (i.e., heater drains).

The condensate pumps take suction from the condenser hotwells and discharge the condensate into one common header which, after passing through the condensate demineralizers, branches into three parallel strings. Each string goes through four stages of low pressure feedwater heaters before joining together into a common header which then branches into two strings and supplies the suction of the steam generator main feedwater pumps (MFP).

Two 50 percent capacity turbine-driven MFPs take suction from the low pressure feedwater heaters and the heater drain pumps and discharge the feedwater into two cross-connected parallel strings. Each string passes through three stages of high pressure feedwater heaters and then joins into a common header which divides into four main feedwater lines, each of which supplies feedwater to one steam generator.

7.2.2 Condensate System

The condensate system returns condensed steam from the main condenser to the steam generator MFP suction (Figure 7.2-2). The system is designed to provide adequate suction for all pumps. The condensate is purified in the condensate demineralizers and heated in the low pressure feedwater heaters. This heating conserves energy and improves plant efficiency. The low pressure heaters are designed to handle 150% of normal flow. This allows a train of heaters to be off-line for maintenance without loss of capacity. Condensate temperature is increased from 126°F to 318°F in four stages of feedwater heating.

7.2.2.1 Main Condenser

The main condenser is a deaerating type of surface condenser with three shells. Each shell is located below its respective low pressure turbine. The tubes in each shell are oriented across the turbine-generator longitudinal axis. Each shell has six tube bundles (Figure 7.2-3).

The condenser is equipped with an automatic makeup and reject system which maintains a normal level in the hotwells. On low water level in the hotwell, a control valve opens and admits condensate from the condensate storage tank into the hotwell through a gravity line. On high water level in the hotwell, another control valve opens to reject condensate from the condensate pump discharge to the condensate storage tank.

7.2.2.2 Condensate Pumps

The condensate pumps are vertical centrifugal pumps. There are three condensate pumps, each with a normal capacity of 33% of the full power flow required. However, if a single pump should trip, each of the remaining pumps will run out and supply 50% of the required flow, and full power operation could be sustained.

7.2.2.3 Condensate Demineralizers

Condensate is delivered through a header to the condensate polishing demineralizers (Figure 7.2-2). Branch connections are provided on the main condensate pump discharge header for the sampling system and seal injection water to the main feedwater pumps, heater drain pumps, and condensate pumps.

The condensate demineralizer system consists of a set of deep bed demineralizers and an automated regeneration system. The system is designed to maintain the required purity of feedwater at all condensate flow rates. During a plant startup, the demineralizers may be used in a short or long cycle recirculation path to clean up the system and establish proper chemistry conditions prior to feeding the steam generators. The condensate demineralizers are usually operated continuously when at power. However, one or more may be bypassed during plant operation or additional demineralizers placed in service during periods of condenser inleakage to maintain acceptable feedwater chemistry for the steam generators.

7.2.2.4 Low Pressure Feedwater Heaters

The low pressure feedwater heaters consist of three strings of four heat exchangers. Each train is designed to handle 50% of full flow, thus permitting full power flow through two heater strings, with one out of service. In addition, a condensate bypass valve is provided around the low pressure heater strings.

The heat exchangers are the straight tube type, with integral drain coolers (Figure 7.24). The shells are carbon steel, and the tubes are stainless steel. For full power conditions, the feedwater temperature is raised from 126°F to 183°F in the first heater, to 218°F in the second, to 284°F in the third, and to 318°F in the fourth heater.

The purpose of preheating the feedwater prior to injecting it into the steam generator is to increase cycle efficiency. Heating steam for the low pressure feedwater heaters is supplied by low pressure turbine extraction steam. By causing steam extracted during expansion through the low pressure turbine to give up its latent heat of vaporization to the feedwater, rather than discarding it to the condenser circulating water, an efficiency gain of approximately 15% is attainable.

The four heat exchangers for each train are physically located in the condenser necks. Train "A" is in the low pressure condenser, train "B" in the intermediate pressure condenser, and train "C" in the high pressure condenser shell. This location saves floor space, shortens piping runs, and minimizes required thermal insulation.

Cascading heater drains is the second source of heat for the low pressure heaters. Drainage from the low pressure heaters is cascaded back through the string before draining to the condenser. Each heater has automatic level control and a dump valve that drains to the condenser on high level.

7.2.3 Feedwater System

The feedwater system preheats, pressurizes, and transports feedwater from the condensate system to the steam generators (Figure 7.2-5). The feedwater system extends from the main feedwater pump suction isolation valves to the inlets to the steam generators. The feedwater system is composed of two 50% capacity, variable speed, turbine-driven feed pumps, two strings of three high pressure feedwater heaters, and the associated valves and piping.

7.2.3.1 Main Feedwater Pumps

The steam generator main feedwater pumps are horizontal, single-stage, centrifugal pumps shaft coupled to their respective steam turbines. They are each capable of runout to 67% flow. The suction sources for the main feedwater pumps are the condensate system and the heater drain tank via the heater drain pumps. Typical suction temperature is 336°F.

7.2.3.2 High Pressure Feedwater Heaters

The high pressure feedwater heaters consist of two strings of three heaters each. A manually operated bypass valve around the heater strings allows continued operation with one string out of service.

The high pressure feedwater heaters are constructed similarly to the low pressure heaters, but have a higher tube side design pressure. Extraction steam from the high pressure turbine provides heating steam for the high pressure feedwater heaters. In addition, cascading heaters drains provide some preheating. The drains from the seventh stage cascade back to the sixth stage, while the sixth and fifth stages drain to the heater drain tank (Figure 7.2-1). The seventh and sixth stage heaters have automatic level control with an automatic overflow which dumps to the low pressure condenser. The fifth stage heater drains directly back to the drain tank without level control.

7.2.3.3 Feedwater Control Valves

Each steam generator feedwater line is supplied with a feedwater control valve which controls feedwater flow to the respective steam generator during normal power operations. The position of the feedwater control valves are automatically regulated to adjust feedwater flow to maintain a desired water level in the steam generators. There is an automatic control system for each of the feedwater control valves called the steam generator water level control system (Chapter 11.1). At low power levels, such as during a plant startup, lower feedwater flows are required. To accommodate these low flow conditions, a small (6") bypass valve is used in place of the larger (14") flow control valve.

7.2.3.4 Main Feedwater Isolation Valves

Each feedwater line contains a motor operated main feedwater isolation valve (MFIV) and a check valve. These valves, the structures in which they are located, and all feedwater piping between the MFIVs and the steam generators are designed to Seismic Category I specifications. The MFIVs are closed automatically by the protection system to isolate main feedwater when a high or low steam generator water level is sensed (indicating a possible malfunction within the system), after a reactor trip, or by an engineered safety features actuation signal.

7.2.3.5 Auxiliary Feedwater System

The Seismic Category I auxiliary feedwater (AFW) system provides feedwater to each steam generator in situations where the main feed system is not available (i.e., after closure of the MFIVs). The capacity of the AFW system provides for reactor decay heat removal, but is not sized to support full power operation. The AFW system is an engineered safety feature and is described in detail in Chapter 5.3.

7.2.4 Mass Flow Balance for Secondary System

Figure 7.2-6 shows a mass balance for a typical secondary system. Because of the steam used for feedwater heating in the high pressure and low pressure heaters, and the steam used in the moisture separator reheater for steam heating, only 53% of the steam from the steam generators enters the main condenser to be condensed. Another 13% enters the condenser as drains from the low pressure feedwater heaters, for a total of 66% of the main feedwater flow entering the suction of the condensate pumps. The remaining main feedwater flow is from the heater drains, which is made up of the drains from the high pressure heaters (16%), the moisture separated in the moisture separator reheater (10%), and the condensed heating steam used in the moisture separator reheater (8%).

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Section 7.3

Main Turbine, MSR, and EHC

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7.3 MAIN TURBINE, MOISTURE SEPARATOR REHEATERS, AND ELECTROHYDRAULIC CONTROL SYSTEM

Learning Objectives:

1. State the purpose of the main turbine.
2. State the purpose of the moisture separator reheaters.
3. State the purpose and function of extraction steam.
4. State the purposes of the electrohydraulic control system.
5. List the control signals used for the following turbine operational modes:
   a. Speed control, and
   b. Load control.
6. List the turbine trip inputs to the reactor protection system.

7.3.1 Introduction

The purpose of the main turbine is to convert the thermal energy of the steam exiting the steam generators into mechanical energy to turn the main generator. Steam from the secondary side of the steam generators of a nuclear steam supply system enters the high pressure turbine of the turbine-generator set, exits to the moisture separator reheaters, and then enters the low pressure turbines. The steam rotates the shaft of the generator by rotating the blades of the turbine cylinders. The generator produces the electrical power of the power plant.

Westinghouse supplies nuclear turbine-generator systems over a load range of 600 megawatts electrical (MWe) to 1500 MWe in three- and four- cylinder configurations for any light water reactor. Described in this chapter is the four-cylinder, tandem-compound, six-flow, nuclear turbine-generator set (Figure 7.3-1) for a four-loop power plant. The turbine-generator can produce up to approximately 1500 MWe with 45-inch last row blades.

7.3.2 Main Turbine

The typical main turbine (Figure 7.3-1) is a four cylinder, 1800 revolutions per minute (rpm) unit with tandem-compound, six-flow exhaust and 45-inch last row blades. This configuration is used typically for ratings in the 1100 to 1500 MWe range.

The main turbine consists of one double-flow high pressure cylinder in tandem with three double-flow low pressure cylinders. Combination moisture separator reheaters (MSR) assemblies are provided between the high and low pressure turbines to dry and superheat the high pressure turbine exhaust steam.

The high pressure turbine is a double-flow element with an impulse stage followed by seven stages of reaction blading in each end of the cylinder. The pressure in the impulse stage (first stage turbine pressure - Pimp) is monitored and used in protection and control circuits as an indication of turbine load. The steam enters the high pressure turbine through two steam chests, one located on each side of the turbine. The steam passes into each steam chest through either of two throttle and governor valve sets. Once inside the high pressure turbine, the steam flow axially in both directions from the inlet chambers, through the impulse stage and reaction blading, to the six exhaust openings (three at each end), then through the cross-under piping to the moisture separator reheaters. Crossover pipes return the steam through either of six sets of reheat stop and intercept valves to the three low pressure turbines (two sets of valves per low pressure turbine).

Each low pressure turbine is a double-flow cylinder employing eight stages of reaction blading. Dry, superheated steam from the MSRs enters each of the three low pressure turbines through the reheat stop and intercept valves at the center of the blade path, travels axially in both directions through eight stages of blading, then downward to exhaust to the condenser. Openings are provided in the high and low pressure cylinders through which steam may be extracted from certain stages of turbine blading. Extraction steam is used to preheat the main feedwater in the high pressure and low pressure feedwater heaters (Chapter 7.2) and reheat the steam as it passes through the MSRs.

7.3.2.1 Control Valves

Steam admission to the main turbine is controlled by positioning of the throttle and governor valves for the high pressure turbine and the reheat stop and intercept valves for the low pressure turbines. Each valve is controlled by the electrohydraulic control (EHC) system through an individually operated valve actuator. The throttle, reheat stop, and intercept valves are normally maintained full open during power operations with load on the turbine being controlled by the positioning of the governor valves by the EHC. All of the valves are automatically closed by the EHC on a turbine trip signal.

7.3.2.2 Rotors

The high pressure turbine rotor is machined from an alloy steel forging and supported by two bearings. An auxiliary shaft is bolted to the governor end of the rotor and is used to drive the impeller of a shaft driven oil pump.

The low pressure turbine rotors are integrally forged with the rotor body. The discs are then machined from the forging to their final configuration.

Flanged, rigid-type couplings are used to connect the rotors of the four turbines and the generator. The rotating element is supported by ten journal bearings and is located axially by a thrust bearing mounted at the governor end of the center low pressure turbine.

Low pressure turbine rotors are interchangeable because of tolerance control achieved in manufacturing. Therefore, spare rotors can be made available to reduce outage time.

7.3.2.3 Turbine Blades

The high pressure blade path consists of a double-flow impulse stage followed by seven stages of double-flow reaction blading. The impulse stage blades are integral with the shroud and machined from a solid block of high strength steel.

The low pressure turbine blade path consists of eight stages of double-flow reaction blading designed to accommodate high exhaust pressure operation. Highly effective interstage moisture removal at the extraction points results in reduced blade erosion and improved steam cycle efficiency.

7.3.3 Electrohydraulic Control System

The turbine is equipped with an electrohydraulic control system (Figure 7.3-2) consisting of an electronic controller and a high pressure fire resistant electrohydraulic fluid supply.

The turbine steam admission valves are opened by the high pressure hydraulic on the valves' actuators or operators. An electronic controller computes error signals comparing actual turbine speed and/or turbine load with reference (desired) values established by the operator. The resulting control signal is transmitted to the electrohydraulic fluid actuator on the turbine governor and throttle valves. The electrohydraulic fluid system provides the power for all turbine valve actuators and positions the governor and throttle valves in response to the electronic control signals from the controller.

The electrohydraulic control (EHC) system provides:

1. Wide range speed control of the turbine from turning gear to rated speed (1800 rpm). This control is accomplished by increasing the desired or reference speed to bring actual shaft speed to its rated value at a controlled, selectable rate.

2. After generator breaker closure, the ability to increase or decrease electrical load at a controlled, selectable rate. Function generators in the turbine valve circuits permit either single or sequential valve operation.

3. The ability to control speed and load from remote locations.

4. A raise-lower backup system to position the turbine valves manually in the case of a control system failure.

5. Bumpless transfer circuits to allow mode changes without bumping the turbine.

7.3.3.1 Controller

The control system operates in speed control mode or load control mode. "Speed control" (Figure 7.3-3) is used to bring the turbine from turning gear operation to synchronous speed. The error between actual and desired speed is used to position the turbine control valves to accelerate the turbine to the desired speed. The control system automatically switches to the "load control" mode (Figure 7.3-4) when a generator output breaker is closed. In load control, the error between actual turbine load and desired load with an input from the speed error channel are combined to operate the control valves.

7.3.3.2 Protective Devices

A mechanical-hydraulic turbine emergency trip system (Figure 7.3-7) is provided to trip the turbine when a problem is detected. This system, which is completely independent of the EHC, is called the auto stop oil system. The auto stop oil system uses oil from the turbine-generator lubricating system (Figure 7.3-2) to maintain the interface valve with the electrohydraulic fluid supply closed. Release (depressurization) of the auto stop oil by any of the turbine trip devices causes the interface valve to open and all high pressure turbine and low pressure turbine steam admission valves to close by dumping the electrohydraulic fluid from their actuators. Low auto stop oil pressure and/or all turbine throttle valves closed signals are sent to the reactor protection system to indicate to the reactor protection system that the turbine has tripped. Under certain conditions, the reactor protection system will generate a reactor trip when a turbine trip has occurred.

The following turbine protective devices will result in a turbine trip (all turbine valves closed by dumping the hydraulic fluid from their actuators when the interface valve is opened by the emergency trip device):

1. Mechanical and electrical overspeed trips,
2. Low bearing oil pressure trip,
3. Low condenser vacuum trip,
4. Thrust bearing trip,
5. Electrical solenoid trips, and
6. Manual trip at turbine governor pedestal.

Turbine overspeed protection is provided by a mechanical overspeed trip mechanism and a redundant electrical overspeed trip system. Both systems ensure that the turbine does not exceed 120 percent of design speed. In addition, an overspeed protection controller causes electro-hydraulic fluid from the governor and intercept valves to dump to the drain sump, thereby closing the governor and intercepts valves at a preselected percent above rated speed to slow the speed of the turbine and attempt to prevent an overspeed trip. The governor and intercept valves reopen when the overspeed condition clears. The electrical solenoid protective trip devices are all included on a mechanical trip block assembly which connects hydraulically to the auto stop oil system. Actuation of any one of these devices, therefore, causes the interface valve to open and turbine valve hydraulic fluid to be dumped to the drain sump.

The electrohydraulic control system will decrease turbine load to a preselected setpoint under certain abnormal plant conditions to maintain the plant within design conditions. These types of load reductions are called "runbacks." The following are several of the turbine runbacks that a plant may be provided with:

1. OP T runback,
2. OT T runback,
3. Loss of condenser vacuum (loss of circulating water pump) runback, and
4. Loss of main feedwater pump.

7.3.4 Moisture Separator Reheaters

Typical combined moisture separator reheaters (Figure 7.3-5) between the high pressure and low pressure turbines remove the moisture in the steam exhausting from the high pressure turbine and reheat the steam to over 100°F superheat. The wet steam enters the moisture removal section and rises through the chevron-type moisture separators where the water is removed and drained to the feedwater system. The dried steam then passes through the reheater section where it is reheated by the highest pressure extraction steam and by main steam withdrawn before the throttle valves. The heating steam is condensed in the tubes and is returned via the heater drain system to the feedwater system. The reheated steam goes to the low pressure turbines and to the main feedwater pump turbines.

7.3.4.1 First Stage Reheater

The first stage reheater has a built in pressure control, because the steam is taken from the high pressure turbine third stage extraction (Figure 7.3-6). As turbine loading increases, the extraction pressure increases proportionally and flow through the reheater tubes increases.

7.3.4.2 Second Stage Reheater

The second stage reheater steam is supplied by the main steam bypass header. Since this steam is high pressure, high temperature steam, a separate control system is provided to throttle steam pressure and flow. This throttling will control the hot reheat steam temperature increase in the moisture separator reheaters.

7.3.5 Summary

The main turbine converts thermal energy of the main steam into mechanical (rotational) energy of the generator rotor resulting in the generation of electrical energy. Extraction steam from the high and low pressure turbines is used for feedwater preheating. The moisture separator reheaters dry and superheat the exhaust steam from the high pressure turbine before the steam enters the low pressure turbines. The turbine electrohydraulic control system provides both speed control and load control of the turbine. On a turbine trip, low auto stop oil pressure and all turbine throttle valves closed signals are received by the reactor protection system.

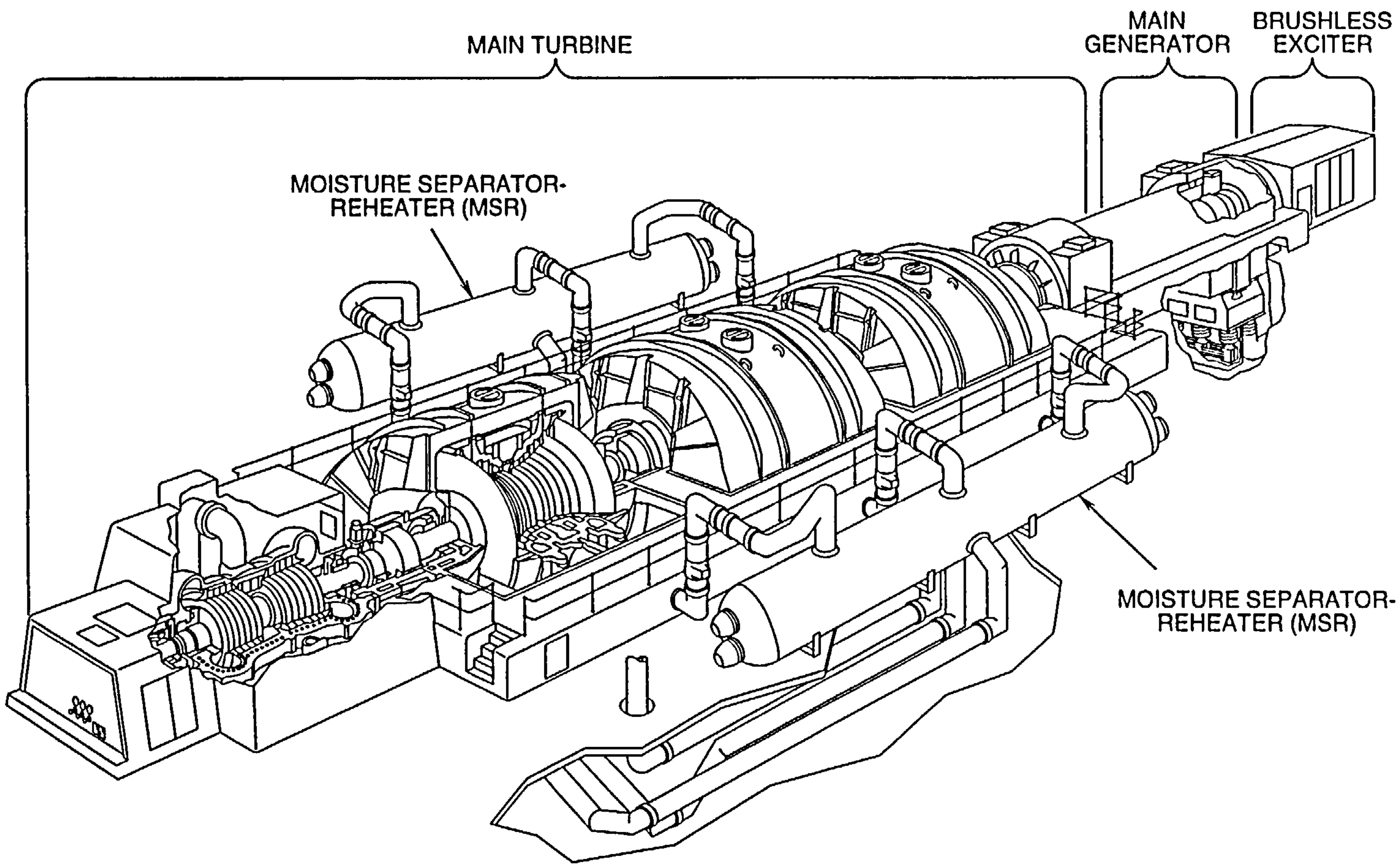

Figure 7.3-1 Turbine-Generator

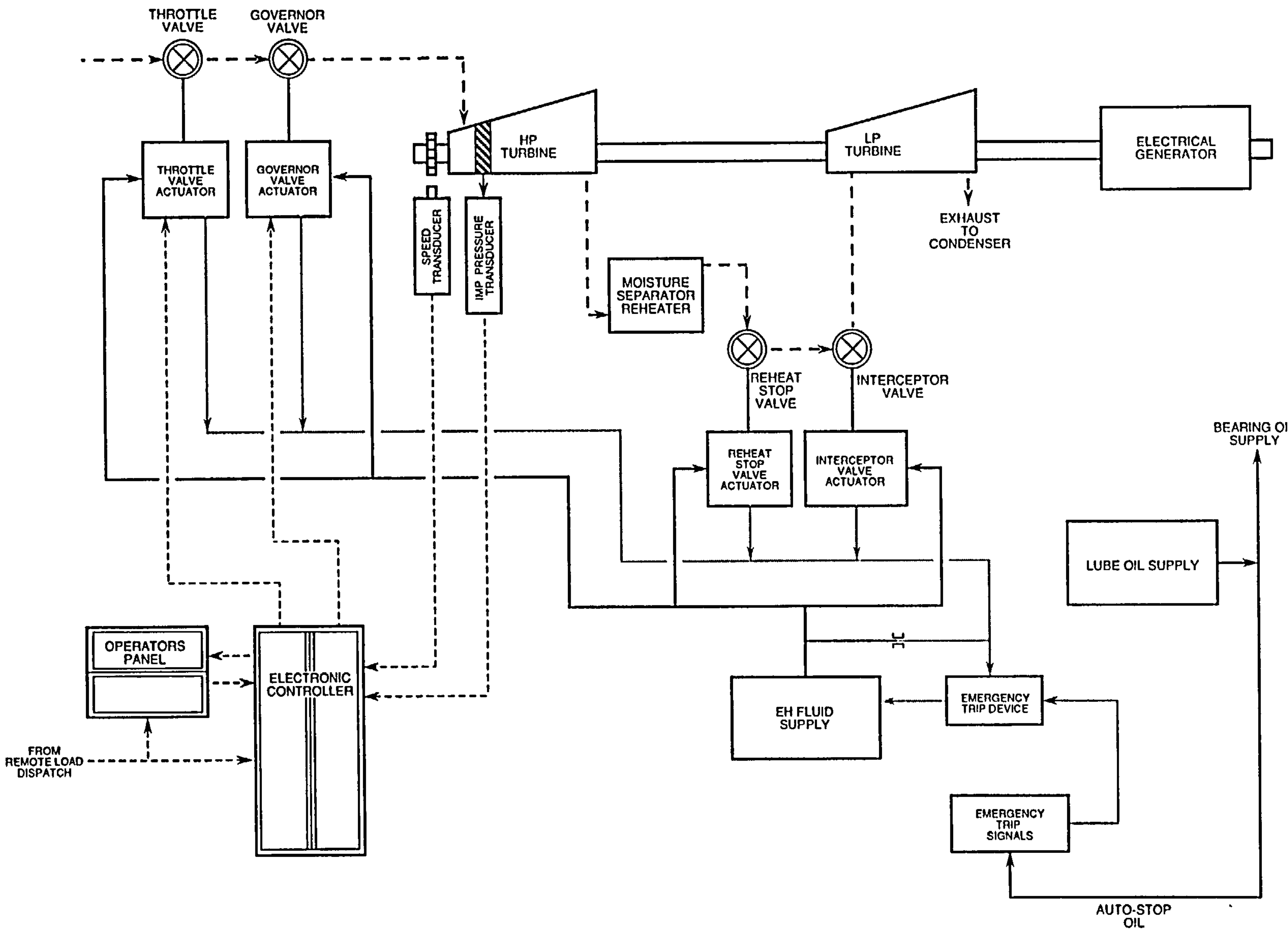

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Figure 7.3-2 Electrohydraulic Control System

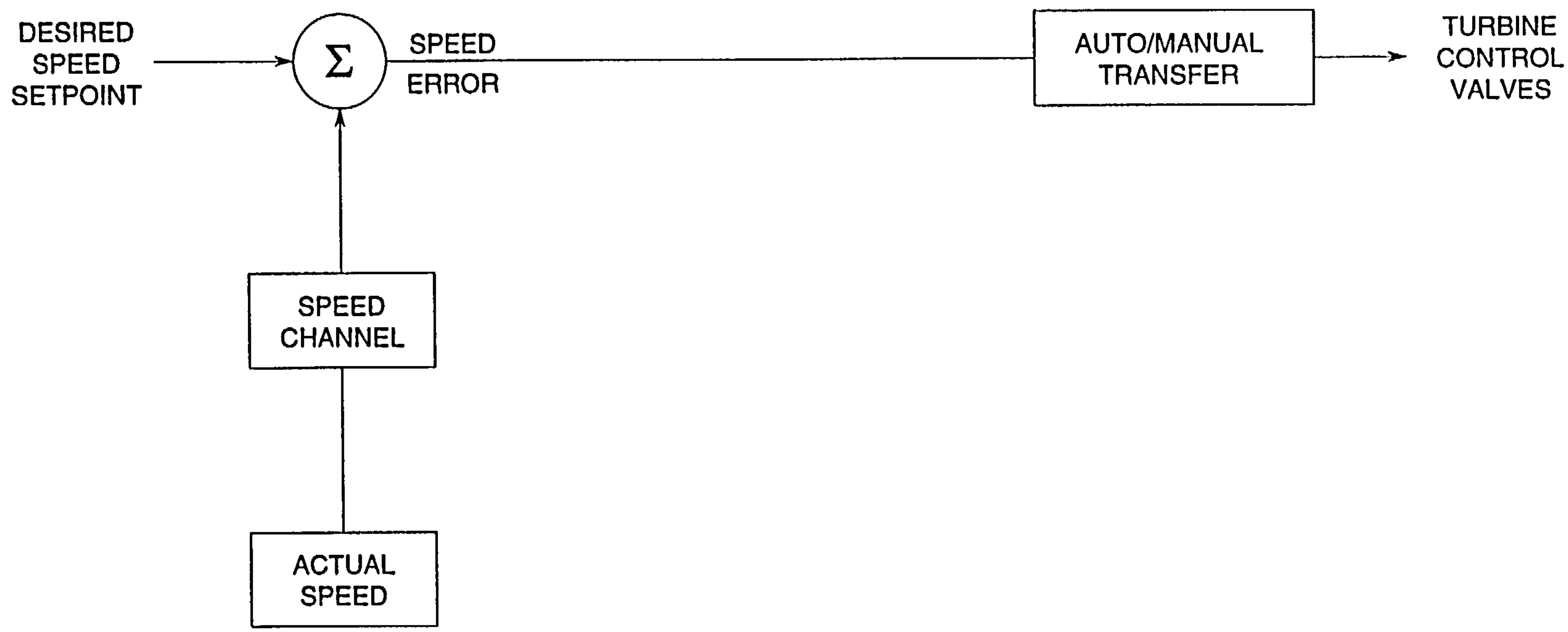

Figure 7.3-3 Speed Control Functional Diagram

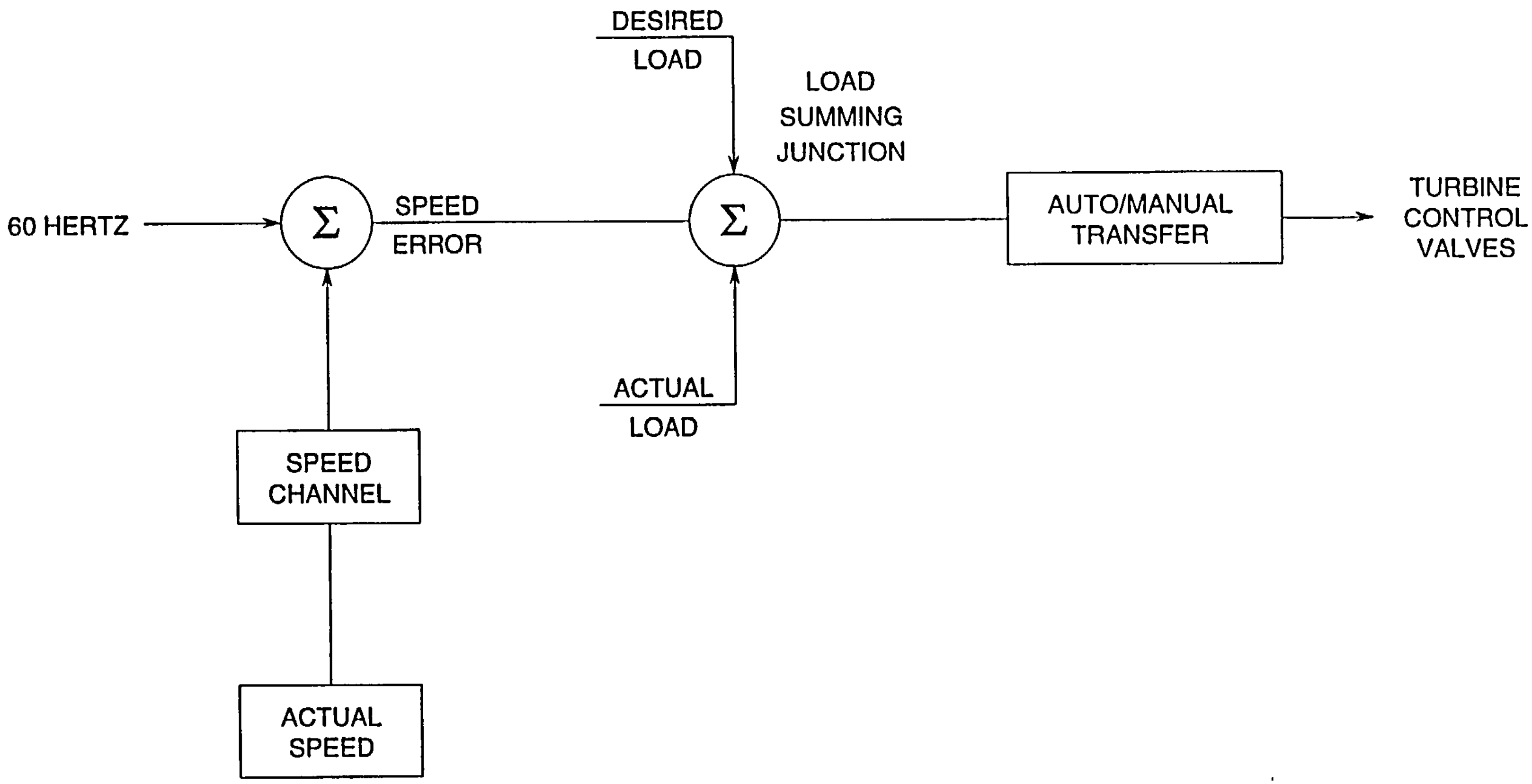

Figure 7.3-4 Load Control Functional Diagram

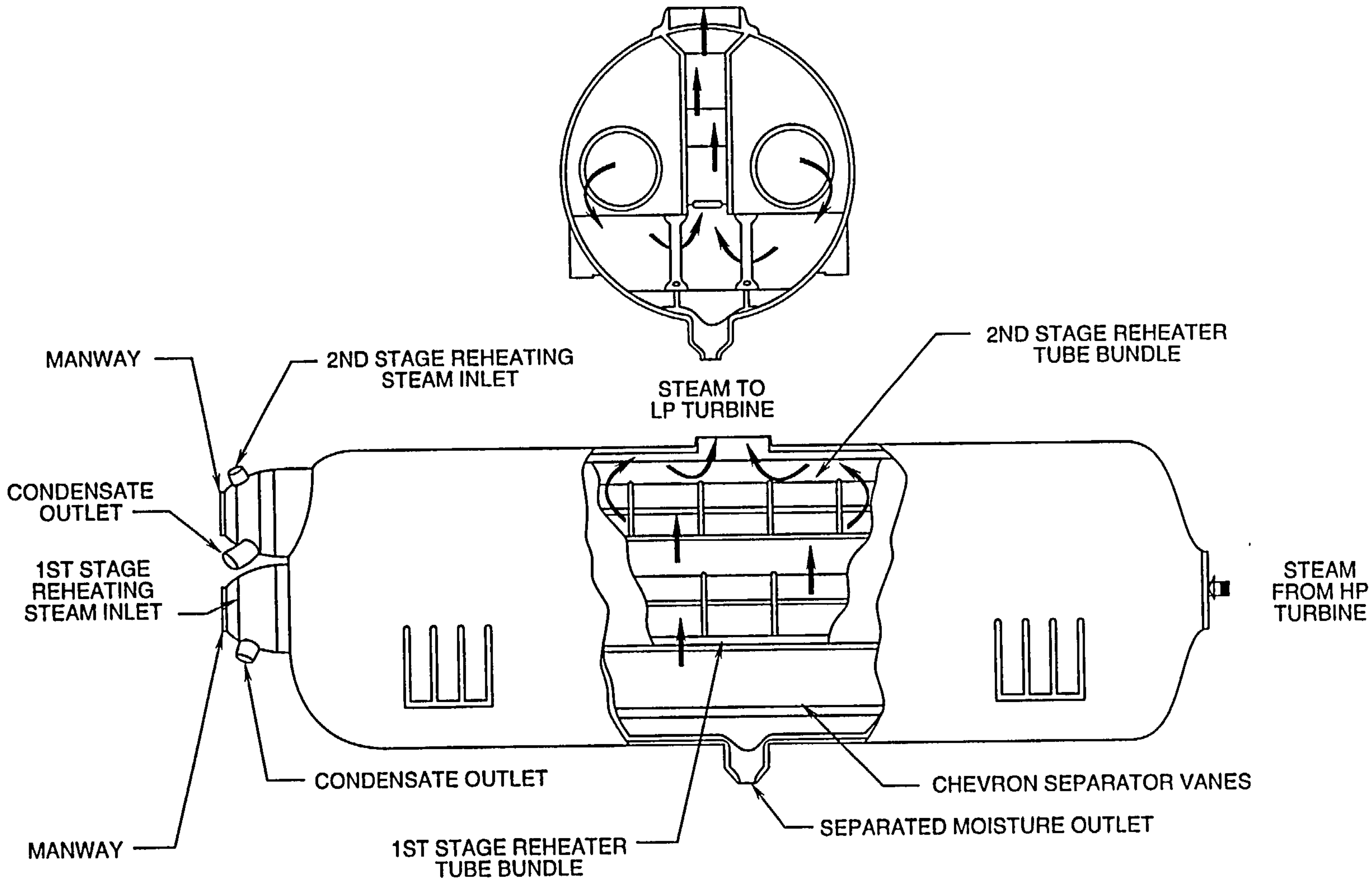

Figure 7.3-5 Moisture Separator–Reheater

698-7

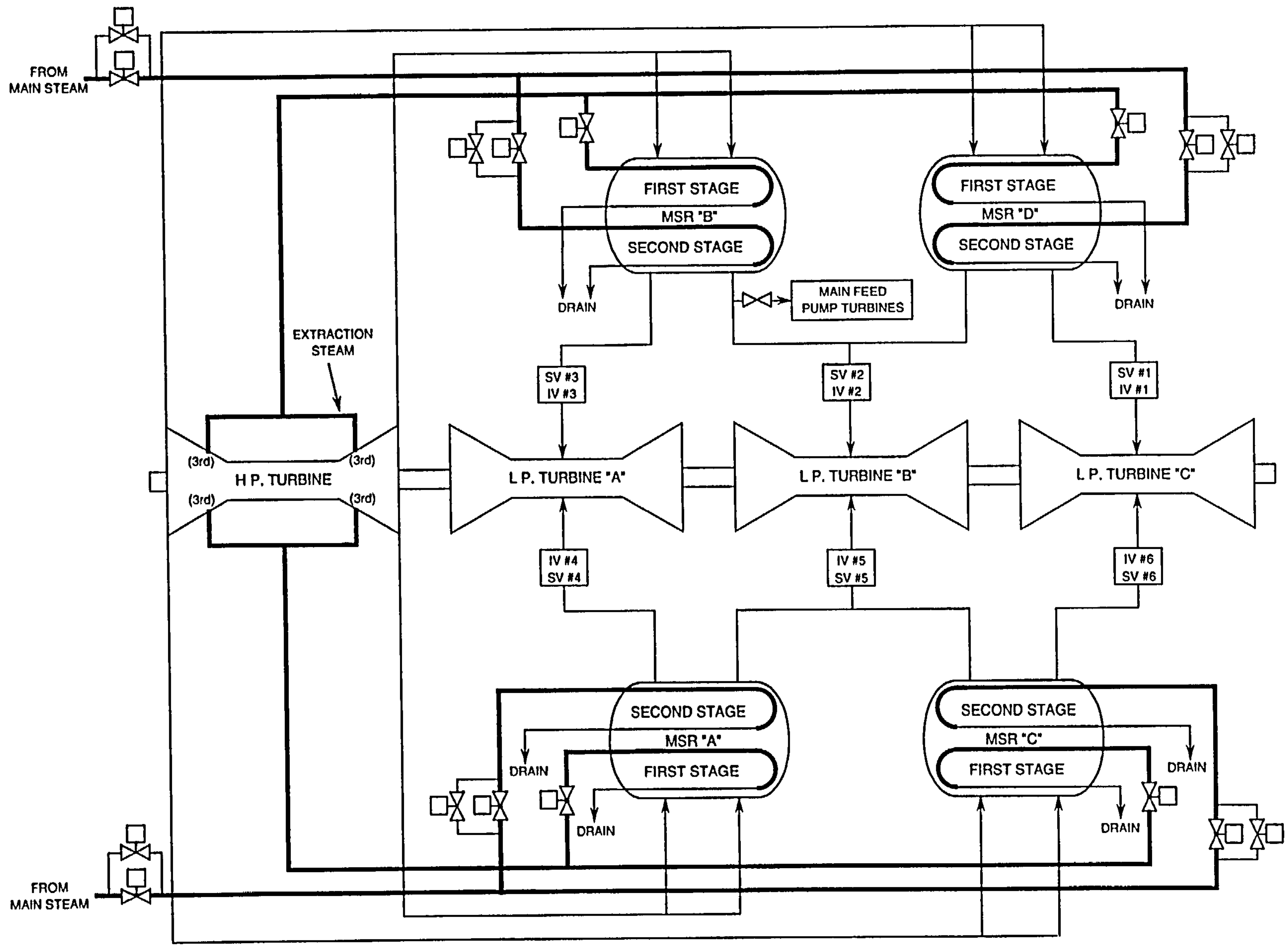

Figure 7.3-6 Reheat Steam and Moisture Separators

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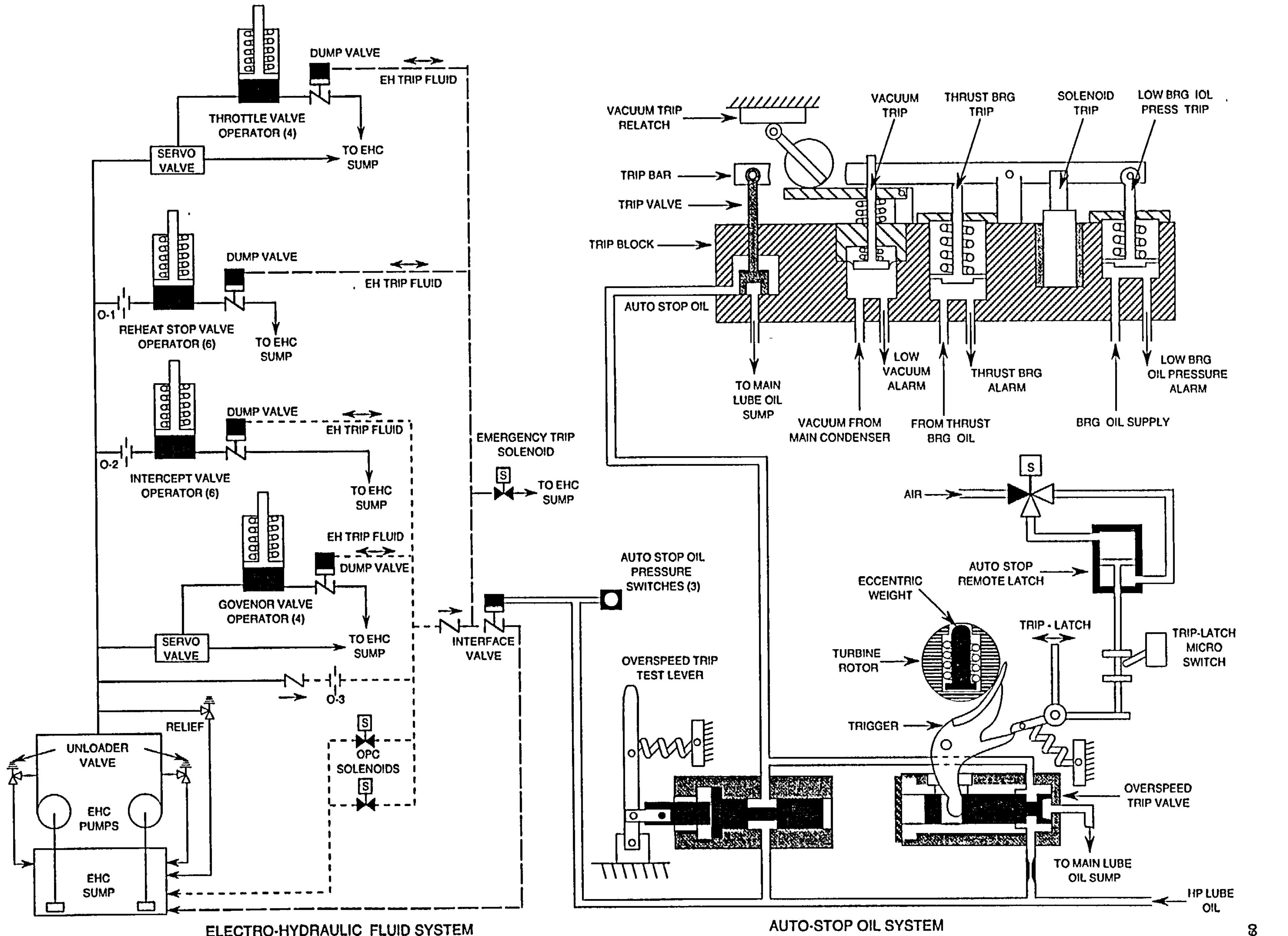

Figure 7.3-7 Electrohydraulic and Auto Stop Oil Systems

Westinghouse Technology Manual

Chapter 8.0

Rod Control System

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8.0 ROD CONTROL SYSTEM

Learning Objectives:

1. State the purpose of the rod control system.
2. Briefly explain how each purpose is accomplished.
3. List the inputs into the automatic rod control system and the reason each input is necessary.
4. Explain how failures in the system are prevented from affecting reactor trip capability.
5. State the purpose of the control rod drive mechanism and explain how it is designed to ensure reliable reactor trip capability.
6. Describe both the individual (analog and digital) and the group demand rod position indication.

8.1 Introduction

The purpose of the automatic rod control system is to maintain a programmed average temperature in the reactor coolant system by regulating the reactivity in the core. Deviation of the average temperature from the program temperature by more than a preselected amount will result in automatic rod movement to return the average temperature (T_{avg}) to program. The speed of this rod movement varies with the size of the temperature deviation. Rod direction either into the core or out of the core is dependent on whether the average temperature is higher or lower than the program temperature.

This system controls the operation of the rod control mechanisms in response to either manual or automatic demand signals. The mechanisms and their associated rod cluster control assemblies (RCCA) are designated as shutdown or control banks. The "shutdown" banks are operated fully withdrawn as a "cocked" source or negative reactivity if an immediate reactor shutdown is needed. The "control" banks may be partially inserted to provide reactivity control during startups and power changes. Operation is programmed such that at one hundred percent power, essentially all control rods are fully withdrawn.

The mechanisms are divided into symmetrical banks which are then subdivided into groups. Five shutdown banks and four control banks, each consisting of one or two groups, are provided in a plant of four loop design. Each group consists of a number of mechanisms whose operating coils are electrically paralleled so that all rods in a specific group step simultaneously. Each bank consists of one or more groups which are moved sequentially so that the groups in a bank are always within one step of each other.

The control rod position indication system continuously senses and displays actual position information for each control rod. In addition to individual rod position indication, the system provides signals corresponding to the demanded bank positions as generated by the automatic rod control system.

8.2 System Description

The automatic rod control system is designed to maintain a programmed average temperature in the reactor coolant by regulating the reactivity within the core. The system is capable of restoring the average temperature to within ±1.5°F of the programmed temperature following design load changes. The design load changes that the rod control system can handle are as follows:

a. 5% per minute ramp increase or decrease,

b. ± 10% step change in load, and

c. 50% step load decrease, with the aid of the automatic initiation and control of the steam of the steam dump system (Section 11.2).

The above load changes will be handled by the rod control system automatically with the reactor power between 15 and 100 percent power. Assurance of stable automatic control below 15 percent of rated power would require the use of a different type of controller than the normal power range controller. Since station operation below 15 percent of rated power occurs only for a short period of time during startup or standby conditions, manual control is acceptable under these conditions. Therefore, automatic rod control below 15% of rated power is not provided.

The rod control system is used to compensate for fast, short term reactivity changes, such as those resulting from power changes and xenon peaking. Compensation for slower, long term effects, such as fuel depletion, gradual xenon and samarium changes, are accomplished by the adjustment of the boron concentration in the reactor coolant system, via the chemical and volume control system (Chapter 4.0).

The RCCAs are separated into two functional categories. These categories are the shutdown banks and the control banks, with each category or type consisting of four individual banks. The shutdown banks are always in the fully withdrawn position during normal operation. They are moved to this position at a constant speed by manual control prior to criticality. The shutdown banks provide a large negative reactivity insertion upon a reactor trip and ensure the reactor remains subcritical. The control rods are the only rods that can be manipulated under automatic control. It is the control rods that are used to change the reactivity in the core, thereby changing the average temperature.

A reactor trip signal causes all rods to fall by gravity into the core. There is individual position indication for each rod cluster control assembly as well as bank position indication (Section 8.5).

8.2.1 Rod Speed

The shutdown banks can be operated only in the "Manual" mode with a preset stepping rate of 64 steps/minute. Each step is 5/8". Control banks may be operated in either "Manual" or "Automatic" control. In the "manual" mode, direction is controlled by the in-hold-out switch and speed may be preset between 8 and 72 steps/minute. In the "automatic" mode, the banks stepping rate and direction is determined by a signal generated by the rod control system.

The time required to complete a single step sequence of a mechanism coil is fixed at 780 milliseconds, which is the maximum reliable sequencing speed of the elctromechanical components of the magnetic jack mechanism. To obtain the desired rod speed, the interval between stepping sequences is varied. For example, an eight step/minute rate is one step every 6.24 seconds with the actual stepping time using 780 milliseconds. The 72 steps/minute rate corresponds to one step every 834 milliseconds with the mechanism stepping time still consuming 780 milliseconds.

8.2.2 Sequencing of Groups Within Banks

To obtain smaller incremental reactivity changes, each control bank is divided into two groups, with the group movement staggered. For example, the group 1 rods in a bank are stepped, and then the group 2 rods are stepped. This effectively splits each bank into two separate banks (groups) to achieve fine control.

8.2.3 Bank Overlap

As the control banks are moved in their prescribed sequence, the banks are overlapped. control bank A is withdrawn until it reaches a preset position near the top of the core. At this point, control bank B starts moving out in synchronism with bank A. Control bank A stops when it reaches the top of the core, and bank B continues until it reaches a preset position near the near the top of the core. At this point, bank C moves out in synchronism with bank B. Bank B motion stops when it reaches the top of the core. Bank C sequencing continues until it reaches a preset position near the top of the core. At this point, bank D begins moving. Banks C and D are withdrawn together until bank C reaches the top of the core. Bank D withdrawal then continues as required for control.

In the overlap region, group 1 rods of each of the two overlapped banks are stepped simultaneously. Similarly, the group 2 rods of the two overlapped banks are stepped simultaneously. At most plants, the overlap is set at 100 steps. This means that for the last 100 steps of a bank's withdrawal travel, it will be moving in overlap with the next sequenced bank.

8.2.4 Control Rod Drive Mechanism Power Supply

Power to the control rod drive mechanisms (CRDMs) is supplied by two motor generator sets operating from two separate 480 volt station service buses. Either rod drive motor generator set is capable of fulfilling all power requirements, and the two are normally operated in parallel. The output of the generators is 260 volts AC.

The power cabinets contain equipment which converts the AC supply to pulsed DC required by the mechanism coils. Each power cabinet can accommodate three groups, with a maximum of four mechanisms per group. Design of the power cabinet permits motion of only one of the groups with the other two groups held in a stationary position.

Power to all rods, both control and shutdown, is supplied via two in-series reactor trip breakers. These breakers are opened by the reactor protection system when a reactor trip is initiated. Opening either breaker removes power to all rod drive mechanisms. When deenergized, the drive mechanisms release the drive shafts, allowing the rods to fall into the core by gravity.

8.3 System Operation

Generally, the operation of the rod control system during a plant startup is as follows:

a. Shutdown banks are sequentially withdrawn to their full out position in "Manual" control.

b. Control banks are manually withdrawn in a programmed sequence (control bank A, B, C, and D). The sequence is reversed for insertion.

c. The rod control system may be placed in automatic operation above fifteen percent power. The direction and speed of rod motion is controlled by the rod control system. If turbine load is increased, reactor power is automatically adjusted to follow. In either the "Manual" or "Automatic" mode, the control rods are moved in the sequence described in "b" above.

8.3.1 Automatic Rod Control

The automatic rod control system (Figure 8-1) maintains a programmed reactor coolant average temperature with adjustments of control bank position for steady state plant conditions. The automatic rod control system is also capable of restoring programmed average temperature following a scheduled or transient step change in load of ± 10% or a ramp change of ± 5%/minute within the range of 15 to 100% power. The coolant average temperature is programmed to increase linearly from zero power to full power conditions (Figure 8-2).

The automatic rod control system consists of two error signal channels which are summed to produce a rod speed demand signal. The two channels used to generate the total error signal are:

a. The deviation between the actual reactor coolant system average temperature (T_{avg}) and the programmed average temperature (T_{ref}). The T_{avg} utilized is the highest calculated T_{avg} determined by an auctioneering circuit. T_{ref} is programmed as a function of turbine load (impulse pressure).

b. The rate of change of the mismatch between nuclear power and turbine power. Since a mismatch of power produced (nuclear) to power used (turbine) will result in a changing T_{avg}, the rate of change of the mismatch is used as a predictive or anticipatory signal.

8.3.2 Temperature Mismatch Channel

The temperature mismatch (T_{ref} - T_{avg}) functions to provide fine control during steady state operations. When power is essentially constant, the power mismatch channel provides no input. Under these conditions, the summing unit just compares T_{ref} to T_{avg} and generates a corresponding error signal. If this error exceeds the prescribed dead band (± 1.5°F), rod motion will be initiated.

8.3.3 Power Mismatch Rate Channel

This circuit provides fast response to a change in load as well as control stability. Turbine load and auctioneered high nuclear power provide the inputs to this channel.

Turbine load and auctioneered high nuclear power are compared in the power mismatch rate unit where the deviation between them is modified as a function of the rate of change of the deviation. The rate unit is designed to provide anticipatory response to a power mismatch. Since the T_{avg} channel provides fine control during steady-state operation, the power mismatch channel should not produce a steady-state error signal. This is ensured by the derivative action of the rate unit, which causes a zero output from this unit during steady-state operation, even though the nuclear power and turbine load signals may not be matched exactly.

This rate of change of the mismatch signal is further processed by the circuit prior to entering the total error summing unit. The error signal is converted from a power mismatch signal to a temperature error signal. This is consistent with the purpose of the rod control system, which is to keep the average temperature approximately equal to the reference temperature.

The summing unit adds the inputs from the two channels (temperature and power mismatch) and produces a total temperature error signal, which in turn feeds the rod speed program.

8.3.4 Rod Speed Program

The rod speed program converts the temperature error to rod motion (Figure 8-3) as follows:

a. Deadband and Lockup

A deadband of ± 1.5°F with a lockup of 0.5°F is employed to eliminate continuous rod stepping and bistable chattering. Rod in motion will be initiated only if the temperature error exceeds -1.5°F. Rod in motion will continue until the temperature error is less than -1.0°F. Lockup is the difference between the temperature error that initiates rod motion and the temperature error where rod motion stops. Rod out motion will be initiated only when the temperature error exceeds +1.5°F. Again, a lockup of 0.5°F is employed.

b. Minimum Rod Speed

The minimum rod speed, fixed by the speed controllers, is 8 steps/minute (5 inches/minute). The minimum rod speed used is based upon stability considerations. Minimum rod speed will be called for when the error signal is between 1.5°F and 3.0°F.

c. Maximum Rod Speed

The maximum rod speed, fixed by the speed controllers, is 72 steps/minute (45 inches/minute). The maximum rod speed used is based upon stability considerations and rod drive mechanism limitations. Maximum rod speed will be called for when the error signal reaches ± 5°F.

d. Proportional Rod Speed

The speed gain in the proportional region is 32 steps/minute/°F. This gain is selected to be consistent with the need for rapid rod motion to limit transient overshoot while preventing overcompensation and oscillation.

8.3.5 Manual Rod Control

In manual rod control, the direction of rod motion is controlled by the in-hold-out switch, and speed is preset at any speed between 6 and 72 steps per minute.

The position of the bank selector switch determines the mode of reactor control. This is a selector switch with the following positions:

a. Shutdown Bank A, B, C, or D - Four separate positions, one per shutdown bank. Rod speed is preset and direction is controlled manually by the in-hold-out switch. Overlap is not used in the shutdown banks.

b. Control Bank A, B, C, or D - Four separate positions. Rod speed is preset and direction is controlled by the in-hold-out switch. Control bank overlap is not maintained.

c. Manual - Rod motion is restricted to control banks only. Rod speed is preset, and direction is controlled manually by the in-hold-out switch. Control bank overlap is automatically maintained.

d. Automatic - Rod motion is restricted to control banks only. Rod speed and direction is controlled by the reactor control system. Control bank overlap is maintained. Automatic rod withdrawal is inhibited at less than 15% turbine load.

8.4 Mechanism Description

8.4.1 Mechanism Operation

The full length rod drive mechanism (Figure 8-4) is a three-coil, electromagnetic jack which raises and lowers the rod control cluster assemblies. The three coils, mounted outside the pressure housing, actuate armatures contained within the housing. The movable and stationary gripper armatures operate latches which grip a grooved drive shaft, which is attached to the control rod cluster. The stationary gripper latches are used to hold the drive shaft in position. The movable gripper latches, which are raised and lowered by the lift coil armature, are used to raise and lower the drive shaft. Each step of the mechanism moves the drive shaft 5/8 inch. The mechanical sequence of operation for one "in" or "out" step is given below.

8.4.2 Mechanical "Out" Sequence

1. Hold on stationary gripper.
2. Latch the movable gripper.
3. Unlatch the stationary gripper.
4. Pull up the lift armature, raising the drive shaft 5/8 inch.
5. Latch the stationary gripper.
6. Unlatch the movable gripper.
7. Drop the lift armature.
8. Repeat Steps 2 through 7 for the next 5/8 inch "out" step.

8.4.3 Mechanical "In" Sequence

1. Hold on stationary gripper.
2. Pull up the lift armature.
3. Latch the movable gripper.
4. Unlatch the stationary gripper.
5. Drop the lift armature, lowering the drive shaft 5/8 inch.
6. Latch the stationary gripper.
7. Unlatch the movable gripper.
8. Repeat Steps 2 through 7 for the next 5/8 inch "in" step.

For complete withdrawal or insertion of the cluster in a twelve foot core, 230 steps are required.

8.5 Rod Position Indication

In Westinghouse plants, there are two methods used to determine rod position. The demand step counters, used for group indication, receives a signal from the rod control system logic cabinet. This system assumes that the rods for a specific group and bank are at their demanded positions. The second method of determining rod position is with the use of individual rod position indication. This system does not assume that the rods have moved, but measures the actual position of each rod.

8.5.1 Group (Demand) Position Indication

The demand position indication is generated within the rod control system. Each time a group of rods is sent a step order by the control system, a digital step counter for that group is moved up or down one step, depending on the direction the rods should have moved. The step counters for each group of rods is displayed on the main control board.

8.5.2 Analog Individual Rod Position Indication (IRPI)

Each control rod has its own position indication detector and readout meter. This system takes advantage of the fact that a transformer secondary output will increase if a piece of conducting metal is placed between the coils of the primary and secondary windings. The detector is a linear transformer which is mounted outside of and concentric with the rod drive pressure housing. The detector consists of alternately stacked primary and secondary coil windings. The rod drive shaft acts as the movable armature of the transformer. The position of the rod drive shaft within the rod position detector determines the amount of coupling between the primary and secondary windings. With the rod drive shaft fully inserted into the core, the magnetic coupling between the primary and secondary coils is small. Therefore, the signal induced to the secondary coil is small. When the rod is withdrawn from the core, the relative permeability of the rod shaft causes an increase in the magnetic coupling between the primary and secondary windings. The magnitude of this secondary output is proportional to the actual rod position. The primary voltage is a constant 12 volts AC. Secondary voltage varies from 8 volts when the rod drive shaft is down (out of the transformer) to 12 volts when the drive shaft is fully withdrawn. This 4 volt change in secondary voltage is proportional to rod position.

The detector AC output is transmitted to a signal conditioning circuit, where it is rectified and amplified. The DC signal is then sent to an individual rod position indicator (one for each control rod) on the main control board, the plant computer, and a rod bottom bistable. The individual rod position channel block diagram is shown on Figure 8-5. The rod bottom bistable is provided to give an alarm if a full length control rod is at the fully inserted position (below 20 steps). A red indicating light and an audible and visual annunciator are provided in the control room.

8.5.3 Digital Rod Position Indication (DRPI)

The digital rod position indication (DRPI) system continuously senses and displays rod position information for each control rod. The system consists of one locally mounted detector stack for each rod, two data cabinets located inside the containment, and one display unit mounted on the control board. Each digital rod position detector stack is a hollow tube with 42 individual coils mounted outside the rod drive shaft travel housing.

When the top of the rod drive shaft is located within a coil, the current flow through that coil increases and is greater than that of the adjacent coil. A sensing resistor in series with each coil develops a voltage drop which will be measured by circuitry in the data cabinets.

Within the two data cabinets (A and B), the voltages across the sensing resistors are continuously sampled. Differential amplifiers inside the data cabinets compare the voltage drops produced by adjacent coils and generate an output according to the difference in voltages. The data cabinet's output is a digital signal equivalent to actual rod position.

The information from the two data cabinets is sent to the control unit inside the main control board DRPI display unit. The control unit receives the information developed by the A data cabinet and the B data cabinet and adds them together to obtain "full accuracy" rod position. This position is sent to the display unit and to the plant computer.

On the display unit, there is one column of lights for each control rod. Each column consists of 40 light emitting diodes (LED). Thirty-eight LEDs are used to indicate actual rod position with an accuracy of ± 4 steps. The bottom LED in each column represents the "Rod at Bottom" position. The top LED is used for a "General Warning" to indicate a problem in the system.

8.6 Summary

The rod control system provides reactivity control to compensate for rapid, short-term variations in reactivity. The control rods are divided into two functional categories, shutdown banks and the control banks. The shutdown banks are fully withdrawn prior to criticality and serve to provide a large amount of shutdown reactivity when a reactor trip is initiated. The control banks provide shutdown reactivity on a trip and provide the reactivity control needed for operation.

To maintain a smooth and relatively constant reactivity addition rate, the control banks are overlapped so that near the end of the bank withdrawal (last 100 steps), the next bank will begin stepping. During this last 100 steps of bank travel, two banks will be stepping in unison.

System operation is determined by the bank selector switch, which may be positioned to select individual shutdown or control banks. Rod control can also be selected for manual or automatic.

In the manual mode, the operator will control the reactivity addition to the core by manually adjusting the height of the control banks. In the automatic position the rod control system determines the rod direction and stepping rate needed to achieve the desired T_{avg}.

The automatic modes of control for this system are provided by two mismatch signals: the temperature mismatch circuit which compares T_{avg} (actual temperature) to T_{ref} (desired temperature) and the power mismatch circuit, which compares nuclear power to turbine power. The temperature mismatch circuit provides fine control while the power mismatch circuit provides an anticipatory signal to start rod movement. Signals received by the logic circuit are directed to the proper power cabinets where the drive mechanism will be sequenced either "in" or "out" of the core.

Power is supplied by two motor generator sets through two series reactor trip breakers to the rod drive mechanisms. Opening either reactor trip breaker will deenergize the rod drive mechanisms, allowing the rods to fall by gravity into the core.

The analog individual rod position indication system uses a linear transformer to continuously measure the actual position of each individual rod. The rod position is transmitted as an AC analog signal which is sent to the signal conditioning module. From this module, the signal is sent to the plant computer, individual position indicators, and to the rod bottom bistable.

The digital rod position indication system uses a detector stack on each rod travel housing that is made up of individual coils. The output signals from these coils are sent to two different data cabinets which monitor coil output voltage. The two adjacent coils that produce the largest differential voltage indicate the position of the rod. The output from the data cabinets are sent to the DRPI display unit which lights one LED for each rod's position, "rod at bottom" lights, and a "General Warning" light.

Group step counters are provided for each group of rods. The step counters display where the rods should be (demanded position) and is derived from the rod control system.

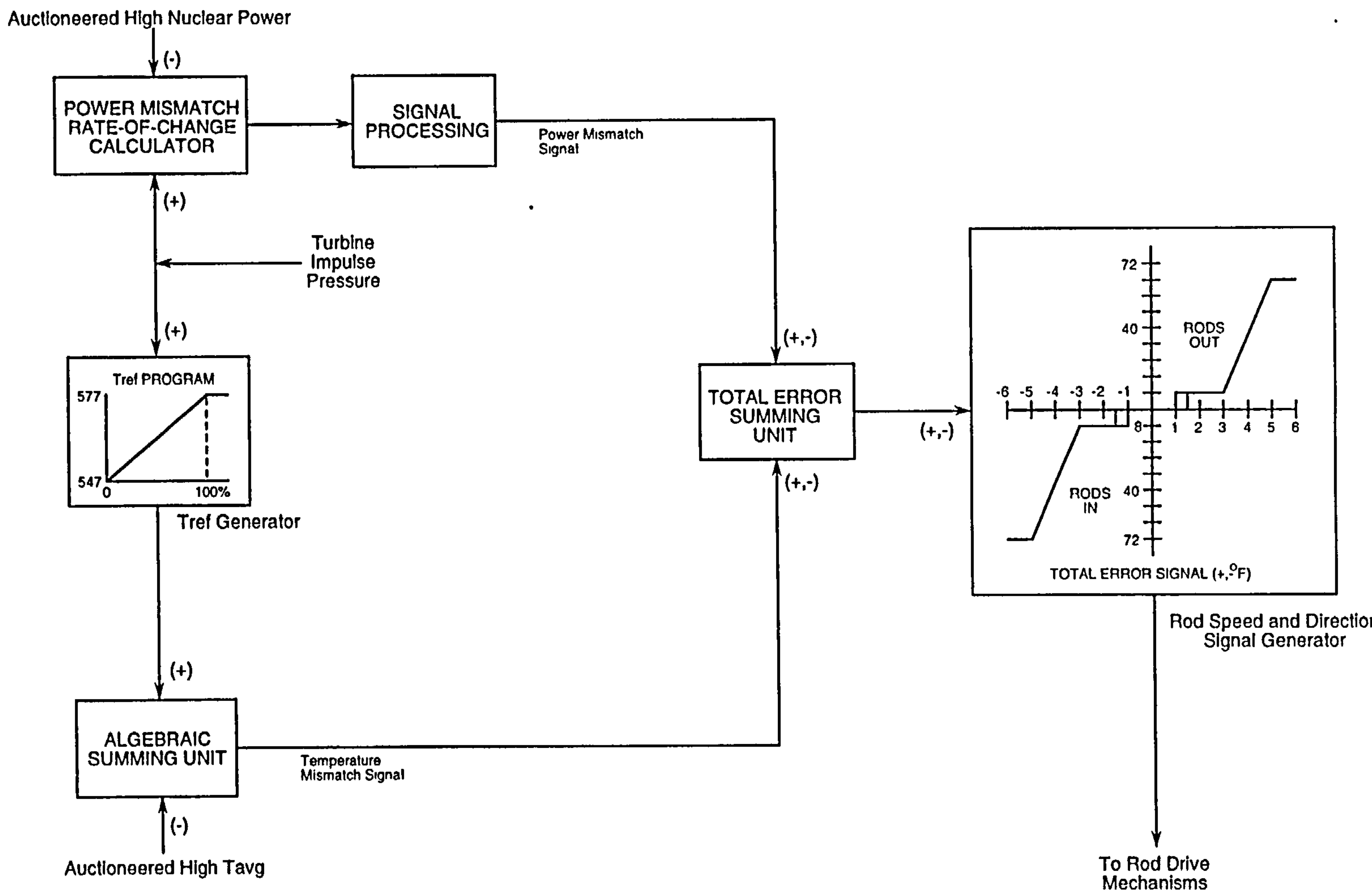

Figure 8-1 Rod Control System Block Diagram

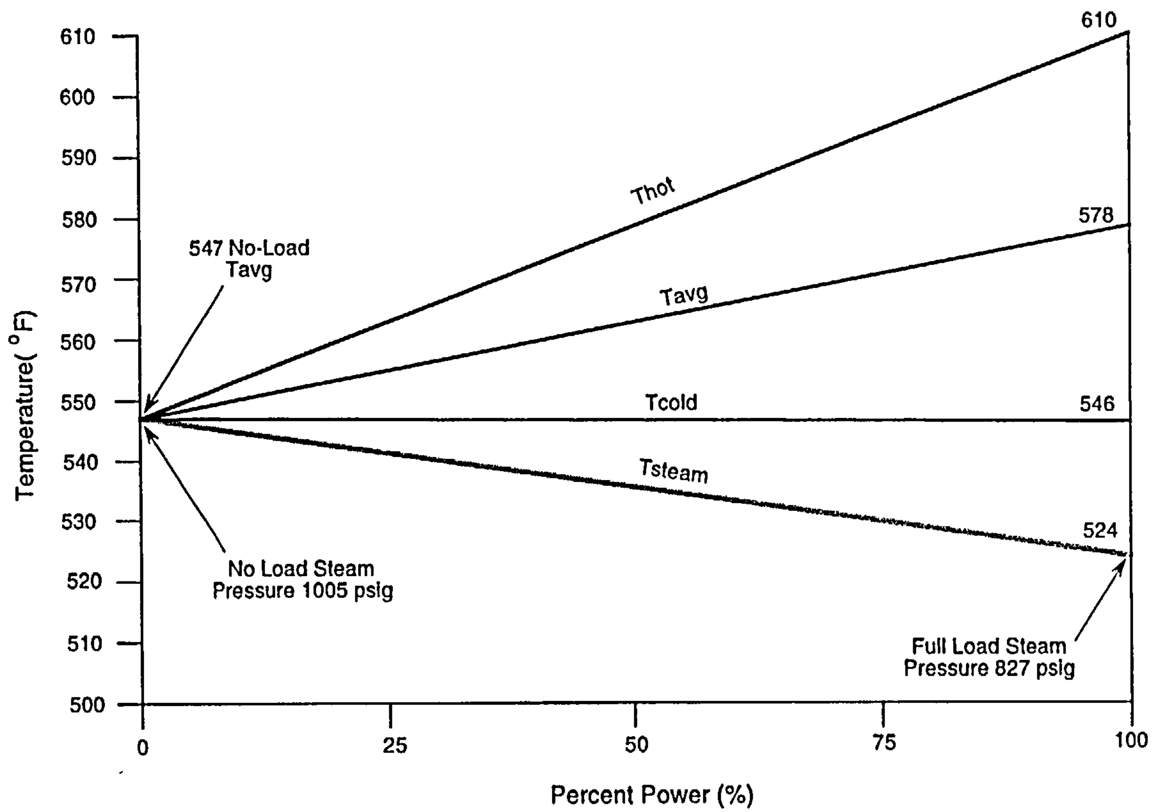

Figure 8-2 Programmed Tavg - Resulting Parameters

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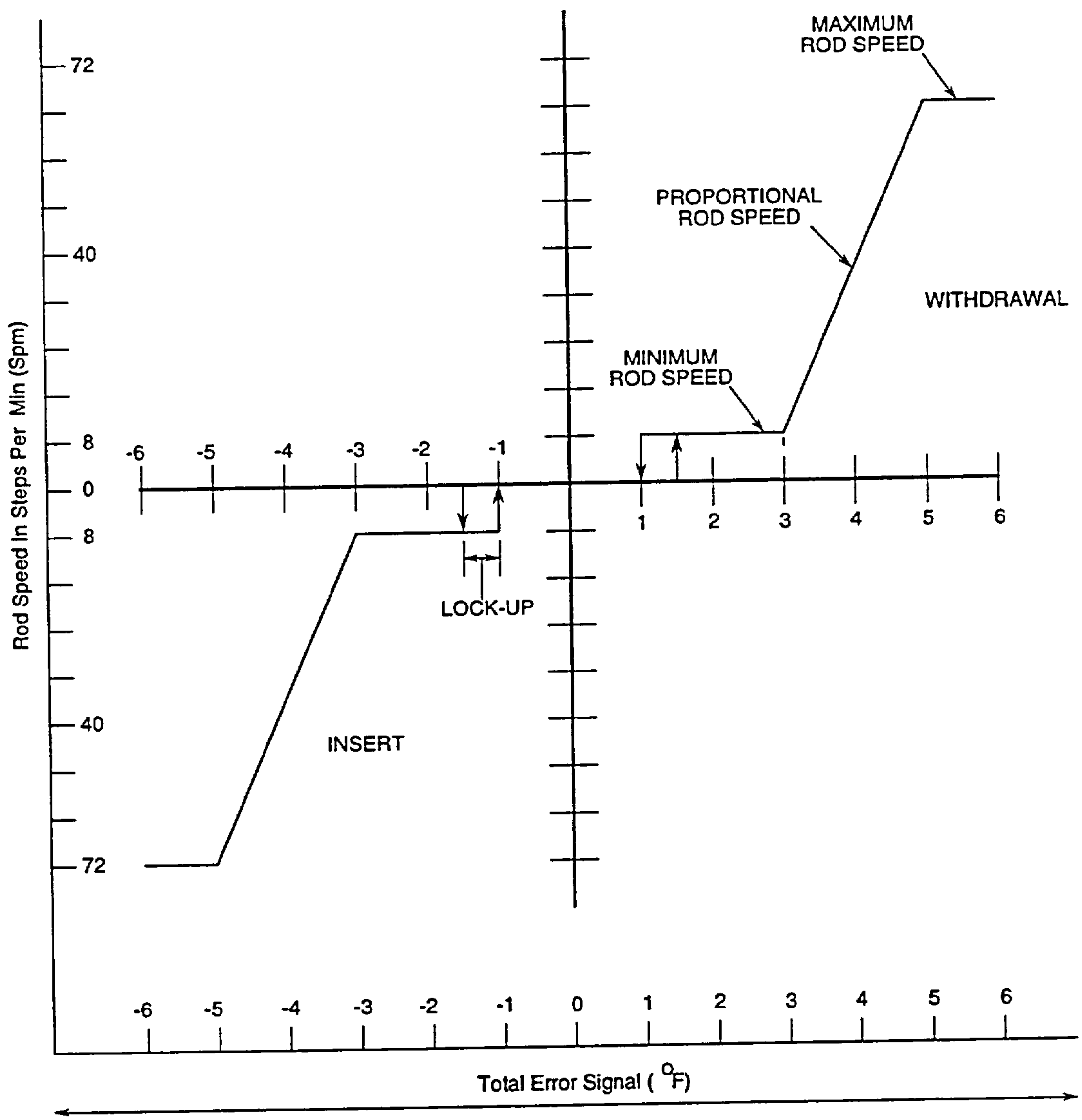

Figure 8-3 Rod Speed Program

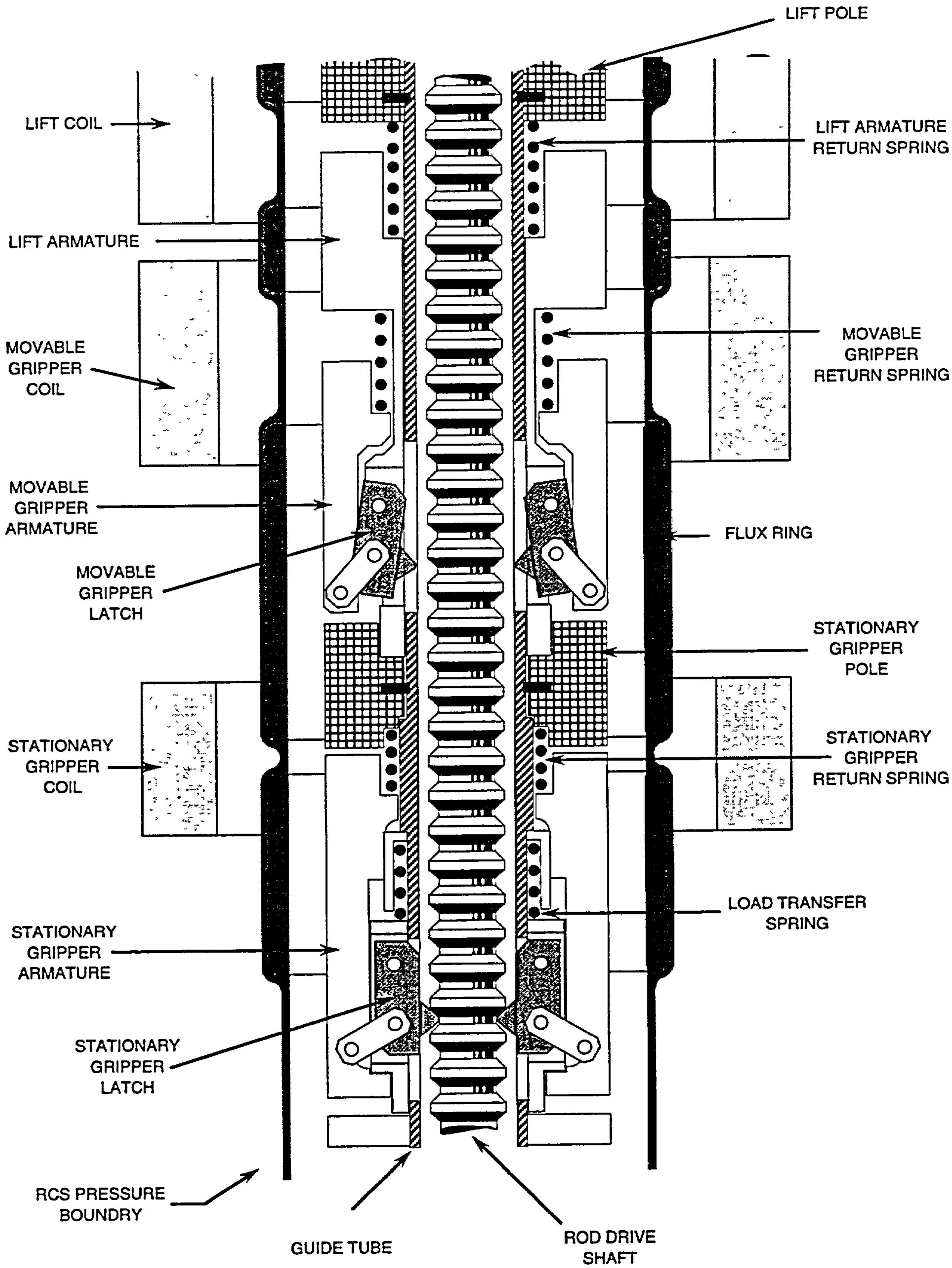

Figure 8-4 Magnetic Jack Assembly

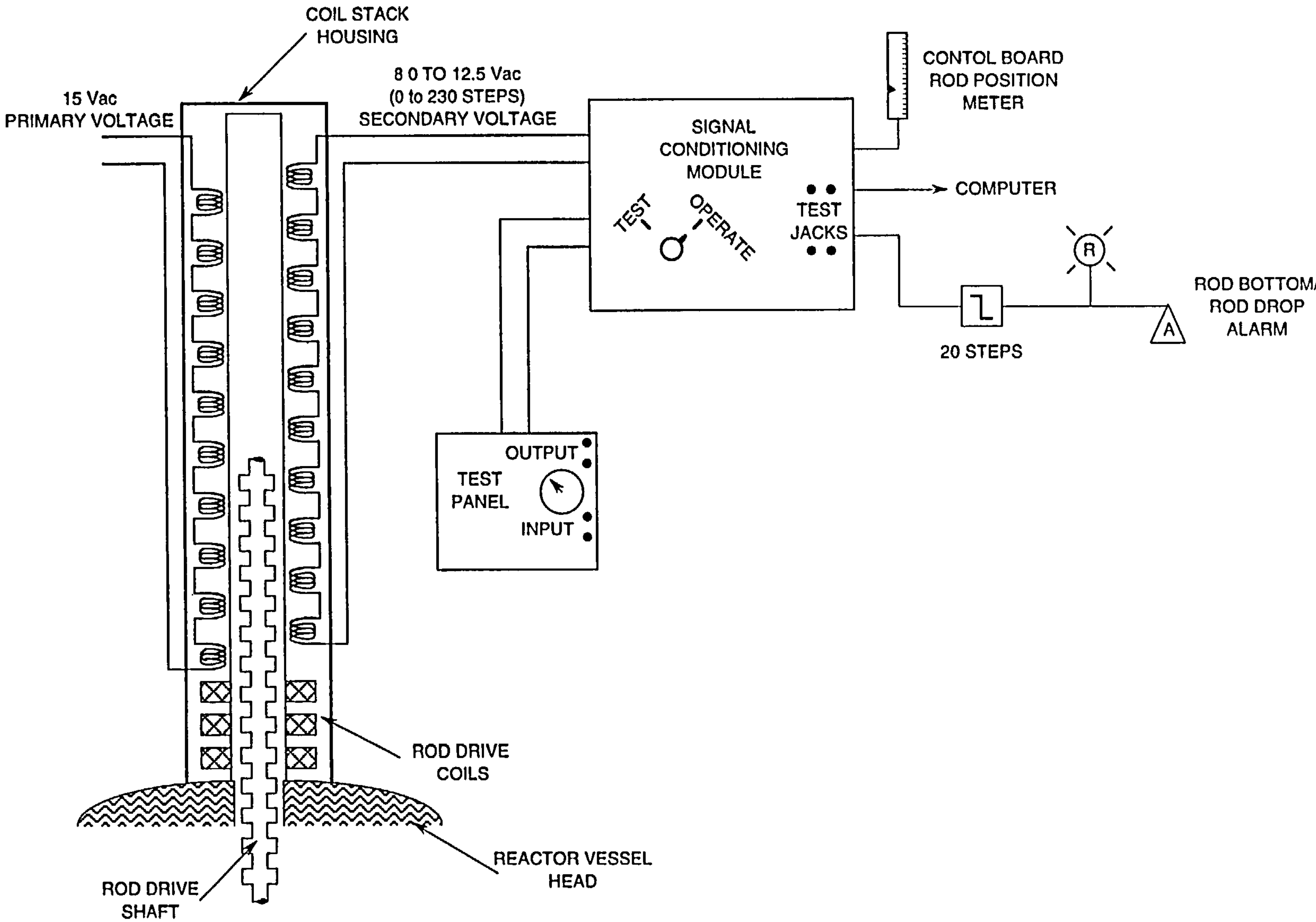

Figure 8-5 Rod Position Indication System

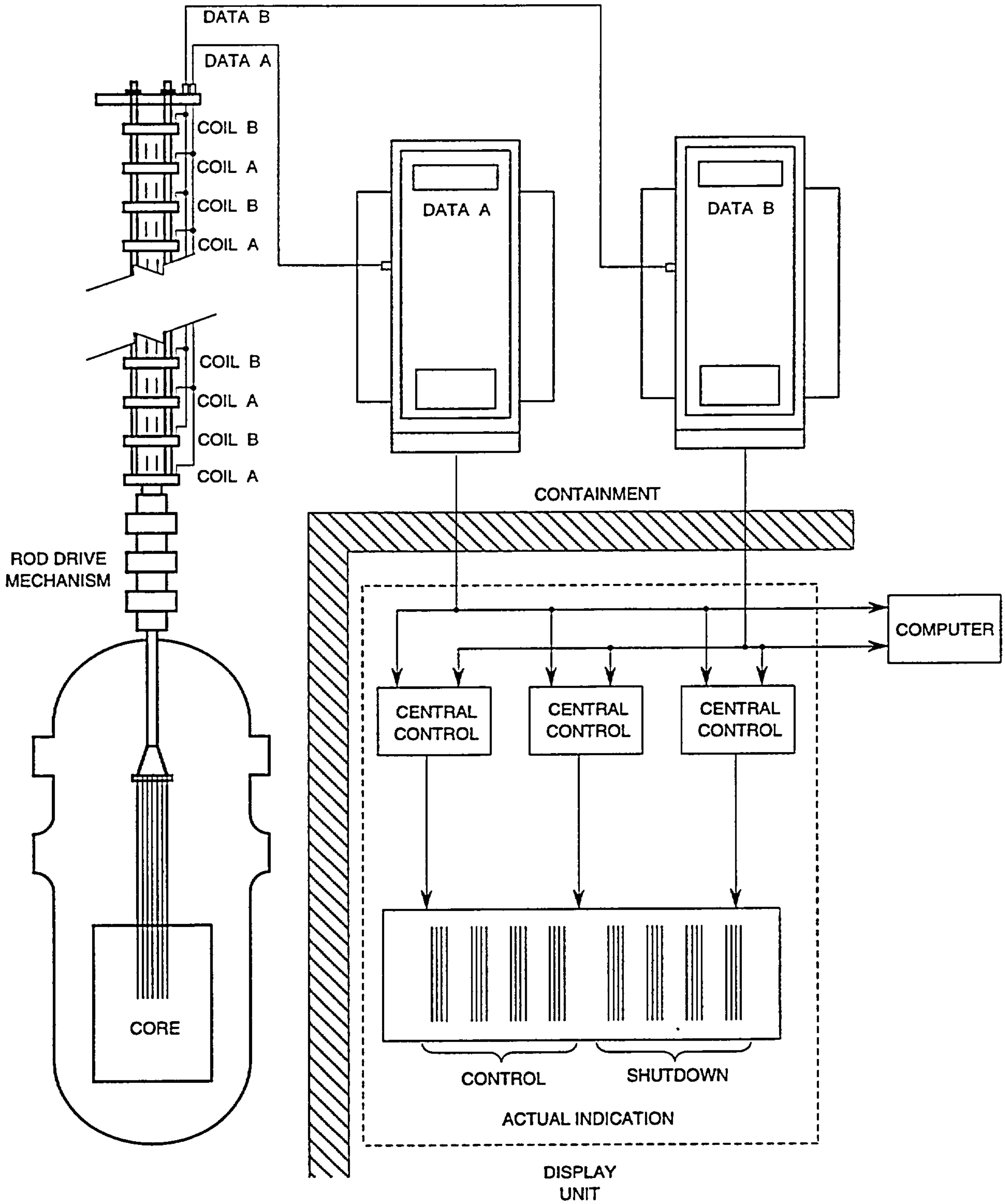

Figure 8-6 Digital Rod Position Indication

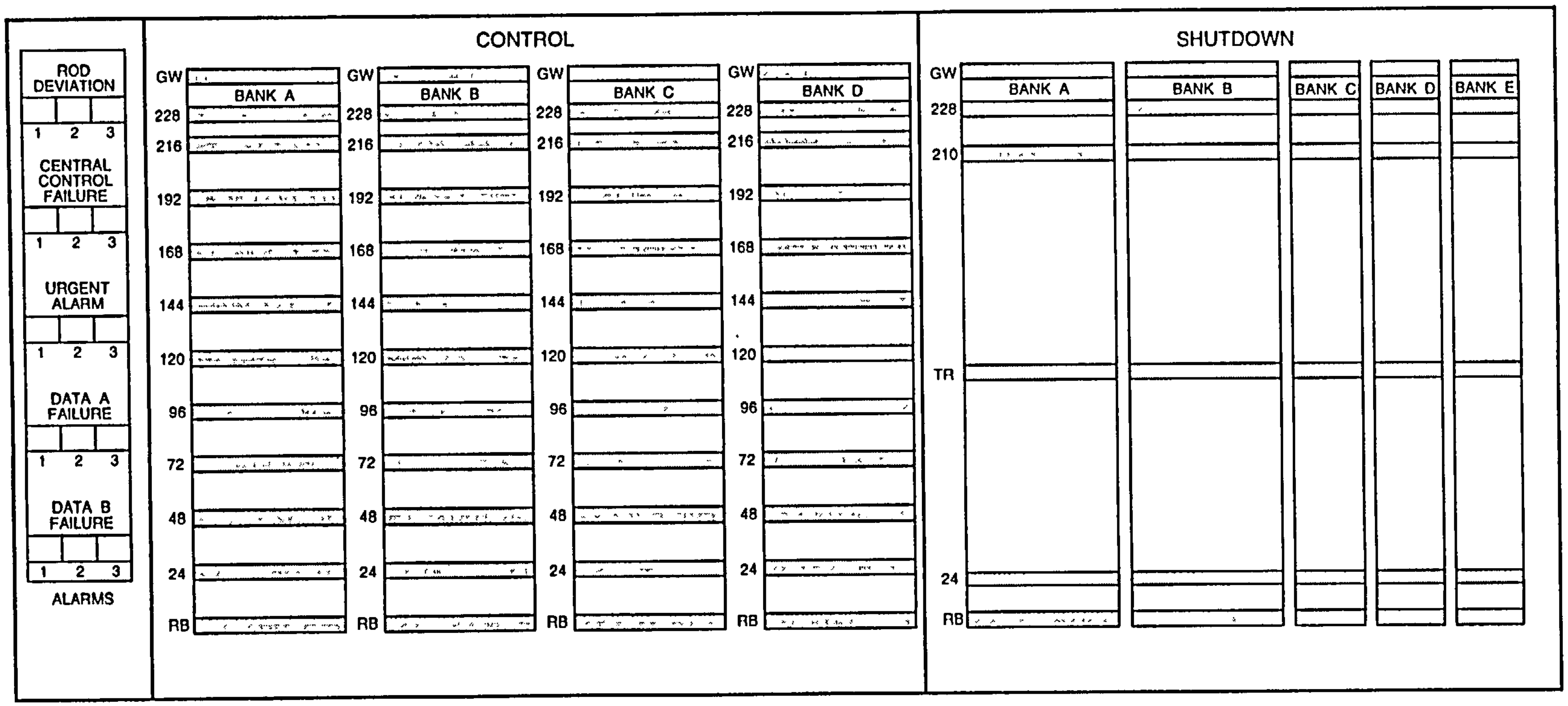

Figure 8-7 DPRI Control Board Indication

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Chapter 9.0

Excore Nuclear Instrumentation

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9.0 EXCORE NUCLEAR INSTRUMENTATION

Learning Objectives:

1. List and state the purposes of the three ranges of excore nuclear instrumentation.

2. Concerning the excore nuclear instrumentation inputs into the reactor protection system:

   a. List the reactor protection system inputs from the excore nuclear instrumentation,

   b. State the purpose of each input, and

   c. State whether each input can be blocked or bypassed.

3. Explain how the excore nuclear instrumentation is capable of detecting both axial and radial power distribution.

4. Explain how the power range is calibrated to indicate percent of full rated power.

9.1 Introduction

The excore nuclear instrumentation system provides various detectors and electronic circuitry to monitor the leakage neutron flux (which is proportional to reactor power) from the reactor at all conditions from shutdown to full power. The power level signals developed are utilized to provide indication, control, and protective functions in the reactor control system and the reactor protection system.

Because the leakage neutron flux varies over a wide range from shutdown to full power, monitoring is provided by several levels or ranges of instrumentation. The lowest level (source range) is a count rate instrument and can measure six decades of leakage neutron flux. The next level (intermediate range) is a current level device and measures eight decades of neutron flux. The highest level (power range) covers about three decades. Figure 9-1 shows the instrument ranges versus thermal neutron leakage flux.

Each range of instrumentation (source, intermediate, and power) provides the necessary overpower reactor trip protection required during operation in that range. Overlap of instrument ranges provides reliable, continuous protection and indication beginning with source level through the intermediate and power levels. Each of the three ranges has overpower protection in the form of high neutron flux reactor trips. The operator can block the overpower trips in the source and intermediate ranges, and the power range high flux (low setpoint) trip during startup. Automatic reset of these trips is provided when power is reduced below that power level at which the operator is permitted to have the trip blocked.

Indication and recording of the various ranges is provided in the control room, including the status of various nuclear instrumentation trip and permissive bistable trip devices.

Neutrons are uncharged particles, and therefore, cannot cause ionization directly. These neutrons must interact with matter by means of a nuclear reaction, which, in turn, will generate charged particles. The charged particles will cause ionization within a gas-filled detector and these ion pairs will produce a voltage pulse or current flow when collected at the electrodes of the detector. The nuclear reaction which produces these charged particles is a boron, lithium reaction in the Westinghouse excore detectors. Basically, the reaction is as follows:

$${}_0N^1 + {}_5B^{10} \dashrightarrow {}_5B^{11*}$$

$${}_5B^{11*} \dashrightarrow {}_3Li^{7+++} + {}_2\alpha^{4++} + \text{energy} + 5e^-$$

The positively charged alpha and lithium particles are attracted toward the anode, and the electrons are attracted toward the cathode of the detector. The charged particles ionize the surrounding gas in the detector, creating a pulse event or a continuous current flow, depending on detector type.

9.2 Source Range

The source range nuclear detectors monitor neutron flux (reactor power) at the lowest shutdown levels and provide indication, alarms, and reactor trips.

Two source range channels are provided, each with its own separate detector, cable run, and electronic circuitry. The detectors utilized are boron-triflouride (BF_3) proportional counters. These BF_3 detectors produce a pulse rate output proportional to the thermal neutron flux seen at the detector. The detectors are located outside the reactor vessel in wells in the primary (biological) shield wall (Figure 9-2).

9.2.1 Detector

The source range detector is a BF_3 gas filled detector (Figure 9-3). In this detector, the incident neutron generates the charged particles Li^{+++} and α^{++}, which produce the ionization. A voltage pulse is generated when the positive and negative ions are collected. A high voltage power supply applies approximately 2000 volts to the detector. This power supply provides the large voltage necessary to cause gas amplification and collect the charged particles from neutron and gamma interactions. The resultant pulses are of varying amplitude, with neutron pulses being significantly larger than gamma pulses.

9.2.2 Circuitry

The pulses generated by the detector (Figure 9-6) are received by the preamplifier, located just outside containment, which optimizes the signal to noise ratio and also couples the high voltage from the power supply to the detector. The preamplifier output is transmitted to the nuclear instrument racks in the control room where the pulse amplifier-discriminator further amplifies the detector pulses and removes the lower amplitude pulses caused by gamma radiation. This method of removing gamma-induced ionization events is called "pulse height discrimination."

The neutron induced pulses are then shaped, amplified, and sent to the log pulse integrator, where the pulse input is integrated and converted into a log level output. The detector and its attendant circuitry has a range of 1 to 10^6 counts per second. The log level is amplified and supplied to several indication and protection functions.

9.2.3 Functions

The log level signal is sent through an isolation amplifier to a control board level meter, recorder, and start-up rate meter. The control board meters and recorder are provided to monitor shutdown neutron levels and flux increases during startup. The startup rate circuit calculates the rate of change of neutron flux level and provides an indication of the reactor startup rate in decades per minute. An alarm and containment evacuation signal are activated by a bistable if shutdown neutron flux exceeds a preset value. This alarm alerts the control room operators and personnel in containment of a positive reactivity addition to the reactor during shutdown conditions. A reactor trip is provided at a level of 10^5 counts per second to protect against startup accidents. This trip is actuated when either of the two channels is greater than its setpoint. To facilitate testing of the channel, this trip can be bypassed.

9.3 Intermediate Range

The intermediate range detectors monitor reactor power from the upper part of the source range through the power range. Eight decades of neutron population are monitored by the intermediate range. To ensure continuity of indication and protection, the intermediate range overlaps portions of both the source and power range nuclear instrumentation. Two intermediate range channels are provided, each with its own separate detector, cable run, and electronic circuitry. The detectors utilized in the intermediate range produce a direct current signal proportional to neutron flux.

9.3.1 Detector

The intermediate range detector is a compensated ion chamber (Figure 9-4). This detector is comprised of two chambers in one case. One of the chambers is coated with boron enriched in the B-10 isotope and is, therefore, sensitive to neutrons and gammas. The second chamber is uncoated and is, therefore, sensitive only to gammas. By connecting the two chambers so that their output currents are electrically opposed, the net electrical output from the detector will be the algebraic sum of the two ionization currents. Mathematically, it could be written as:

$$i_n + i_{gamma} = \text{neutron + gamma current}$$

$$i_{gamma} = \text{gamma current}$$

$$i_{total} = (i_n + i_{gamma}) - i_{gamma}$$

$$i_{total} = i_n$$

Positive high voltage and negative compensating voltage is supplied from the intermediate range circuitry drawers to each compensated ion chamber. The compensating voltage is adjusted to cancel the effects of the gamma flux at the detector so that the output is proportional only to neutron flux.

9.3.2 Circuitry

The output of the compensated ion chamber is a continuous current level; therefore, no signal conditioning is necessary prior to the log current amplifier. This device provides a logarithmic output from the neutron level signal input. This log signal is used as the input to various indication, alarm, permissive, and protection circuits (Figure 9-6).

An isolation amplifier couples the log level signal to a control board meter, recorder, and startup rate circuit meter. The intermediate range meters and recorder indicate in units of current from 10^{-11} to 10^{-3} amps, a total of eight decades.

9.3.3 Functions

A bistable output is provided for the source range permissive (P-6). When the neutron level exceeds the P-6 setpoint, the operator may "block" the source range reactor trip and deenergize the source range detector voltage.

The P-6 setpoint is chosen such that the intermediate range must be indicating properly before the source range can be deenergized. When neutron flux is decreasing during a shutdown, P-6 will automatically reinstate source range detector voltage and the source range trip. If the operator fails to manually block the source range trip during a startup, the reactor would trip when the source range trip setpoint is exceeded. This trip reduces the possibility of an inadvertent startup.

If the current output signal from the intermediate range increases to a level equivalent to 25% power, a reactor trip is initiated. Either channel above this setpoint of 25% will initiate the reactor trip. Like the source range trip, this trip is provided to prevent an accidental reactor startup. This trip can be blocked by the operator when a permissive is received from the power range channels at 10% power. In addition to the trip function at 25% power, the intermediate range also provides a control rod withdrawal block at 20% if the trip has not been blocked by the operator. Both the trip and rod stop can be bypassed to facilitate channel testing.

9.4 Power Range

The power range detectors provide indication of reactor power from zero to 120% of full rated power, along with indication of the axial and radial distribution of that power. The power level signal is also used to generate various control, permissive, and protective features necessary for safe and efficient plant operation.

The power range nuclear instrumentation consists of four independent power range channels. Each channel monitors a "quadrant" of the core by means of an upper and lower detector (Figure 9-2). Because there are four channels and protection features require a two out of four logic, there are no bypasses necessary or provided for testing power range channels.

9.4.1 Detector

The power range detector is an uncompensated ion chamber (Figure 9-5). The detector consists of a single cylindrical chamber whose operation is identical to that of the boron lined chamber of the compensated ion chamber. This chamber is sensitive to both gammas and neutrons; however, in the power range of operation, the neutron flux level is many times greater than the gamma flux, and therefore, no gamma compensation is required.

9.4.2 Circuitry

By providing an upper and a lower detector (Figure 9-7) for each of the four channels, axial flux distribution is obtained. Axial flux is the relative power in the top-to-bottom direction. In a similar manner, an indication of radial flux distribution may be detected by comparing the detector(s) of one channel with the detectors of the other three channels. This produces a profile of power distribution in the radial direction. When the two detector outputs of a channel are summed, a signal proportional to total reactor power is obtained.

9.4.3 Functions

The power range channel outputs are of two types; individual detector output or total channel output. Their functional uses are similarly arranged below.

a. Individual detector output functions:

1. Δ Flux - This parameter is an indication of axial power distribution and is defined

as the top (A) detector output minus the bottom (B) detector output expressed in percent. Therefore, a positive Δ flux indicates more power being produced in the top half of the core, and a negative Δ flux indicates more power being produced in the bottom of the core. Most plants place severe restrictions on Δ flux to insure an even distribution of power throughout the core.

2. Upper Detector Current Comparator - The current output from all upper (A) detectors are compared to produce a radial tilt factor called "Quadrant Power Tilt Ratio." The circuit compares the highest of the upper detector currents to the average of all the upper detector currents. An alarm is provided if a preset limit (approximately 102%) is exceeded.

3. Lower Detector Current Comparator - This circuit is the same as "2" above, except that the lower (B) detectors are compared to each other.

4. Output from each detector is also supplied as input to the OPΔT and OTΔT calculators used in the reactor protection system (Chapter 12).

b. Total reactor power functions:

The upper (A) and lower (B) detector currents are summed and amplified to produce a linear signal proportional to total reactor power. This reactor power signal is calibrated to indicate the power level as calculated from a secondary heat balance (calorimetric). Each channel's summing and level amplifier is adjusted so that the channel's output matches the power output calculations. The power range channels provide the following functions:

1. Control Board Power Meter and Recorder - Indication in percent of full rated reactor power.

2. Overpower Recorder - A wide range accident recorder to record overpower transients up to 200%.

3. Channel Current Comparator - Compares the total power output from all four channels and alarms if their deviation exceeds a present amount. This provides an indication of a channel not properly calibrated.

4. Rod Control System Power Mismatch Circuit - A control signal used in the rod control system which computes nuclear and turbine power mismatch to determine the direction and speed of rod motion.

5. High Power Trip - (Low Setpoint) - A reactor trip will occur if power level exceeds the preset value (25%), on two of four channels, and the trip is not blocked. Blocking is a manual action and is interlocked with the "Nuclear at-Power" permissive (see function 9 below). This trip is provided as inadvertent startup protection.

6. High Power Trip - (High Setpoint) - A reactor trip is also provided from power range instrumentation at 109% to protect the core from an overpower condition. This trip is a two of four logic and cannot be blocked.

7. Rate Trips - If the rate of change of reactor power exceeds a preset value in either the positive or negative direction, a reactor trip will occur. The negative rate trip setpoint is chosen so that one or more dropped control rods will cause a trip. The positive rate trip setpoint is chosen so that an ejected rod will cause a trip. The logic for both rate trips is two of four.

8. Power Range Rod Withdrawal Stop - A rod withdrawal stop is provided at 103%, a point slightly below the high power trip, to attempt to terminate a power excursion before the high power trip setpoint is reached. This occurs when one of the four channels is at setpoint (one of four logic).

9. Nuclear at-Power Permissive (P-10) - This permissive is actuated when nuclear power is above ten percent on two of four channels. This setpoint ensures proper overlap between intermediate and power ranges before power level is increased. P-10 allows manual blocking of the intermediate range flux trip, the intermediate range rod withdrawal block, and the power range high power (low setpoint) trip. If power is reduced below the P-10 setpoint, the manual blocks are automatically removed, and the above mentioned trips and the rod withdrawal block are reinstated. P-10 is also an input to the At-Power Permissive (P-7), which will be discussed in Chapter 12.

10. Three-Loop Flow Permissive (P-8) - At a power level above the P-8 setpoint (usually 35%), the loss of flow in a single reactor coolant loop will cause a direct reactor trip. This permissive ensures a sufficient amount of flow through the core for the existing power level.

11. Turbine Trip - Reactor Trip Permissive (P-9) - At a power level above the P-9 setpoint (usually 50%), a turbine trip will cause a reactor trip to limit the resultant thermal transient in the reactor coolant system.

9.5 Summary

In order to accurately monitor core conditions over a wide range of neutron flux levels, three separate ranges of instrumentation are provided. The detectors for each range are located in the biological shield around the reactor vessel and measure leakage neutron flux. The influence of gamma events on the detector outputs is eliminated by pulse-height discrimination in the source range, and by application of a compensating voltage in the intermediate range. Gamma events are ignored in the power range. Inadvertent startup protection is provided in each range in the form of level trips. The operator must deliberately block each of these trips during a startup. Power range channels are arranged to provide total power, axial flux difference, and radial tilt information. This information is supplied to control board displays and to the reactor protection system (Chapter 12). Control signals to the rod control system also use the information provided by the power range instruments.

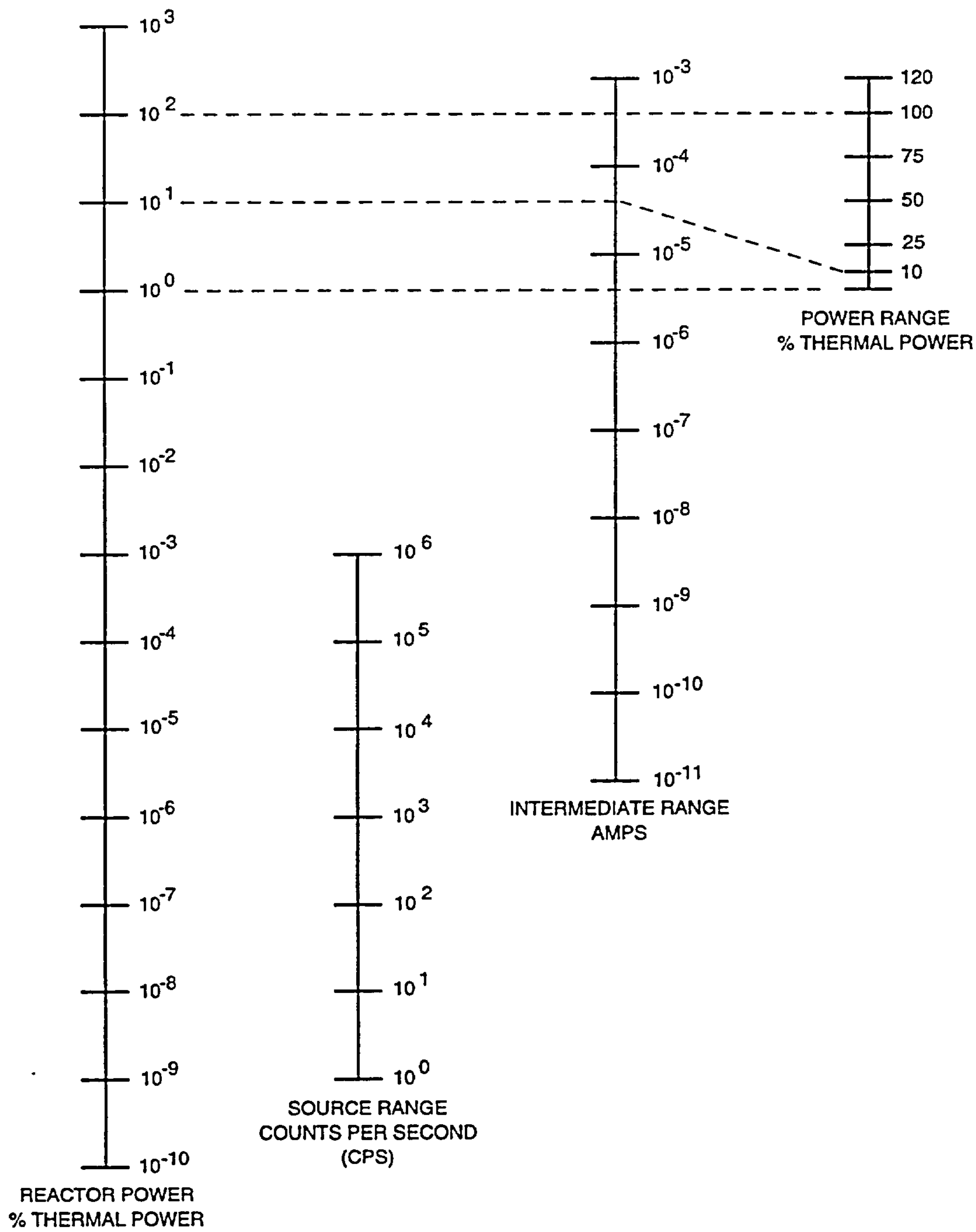
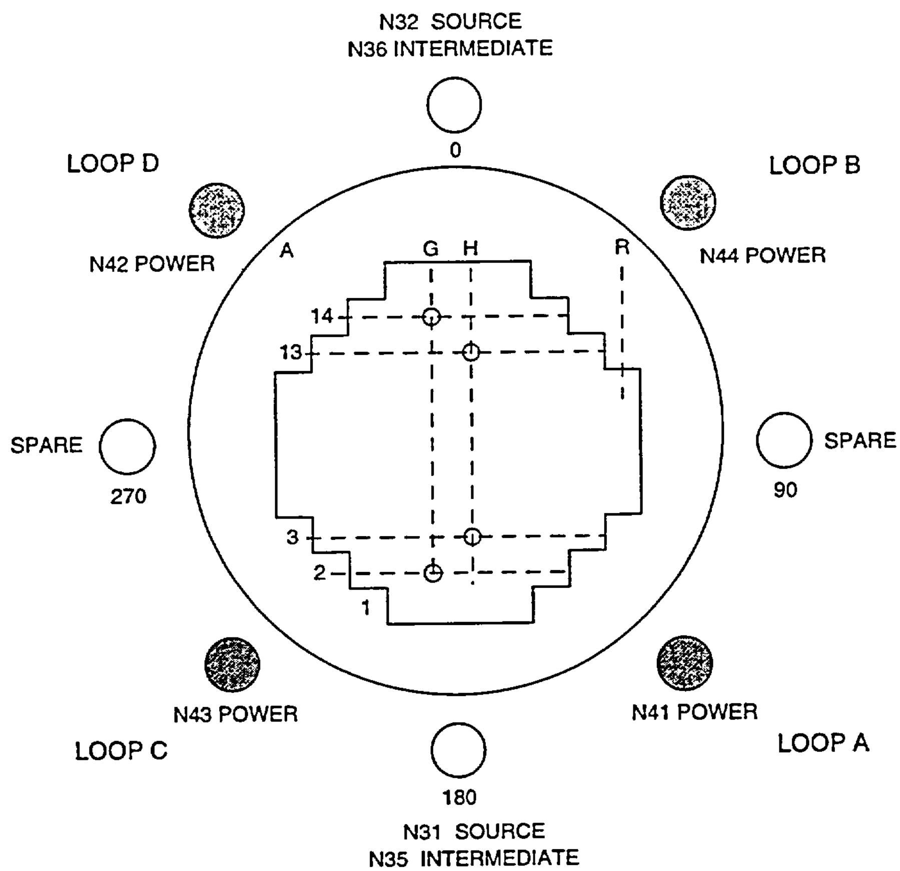
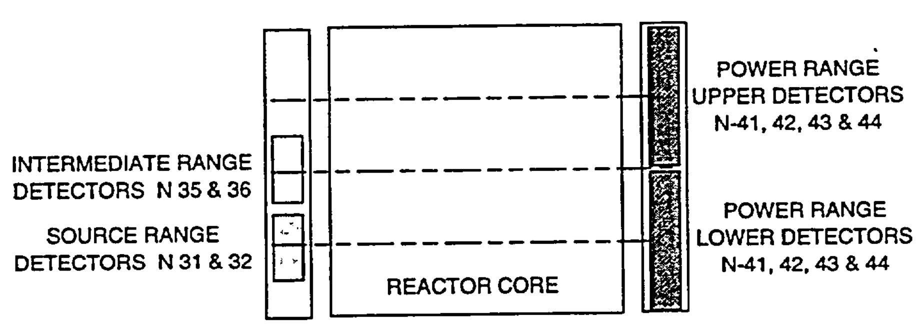


Figure 9-1 Neutron Detectors Range of Operation



NUCLEAR INSTRUMENTATION SYSTEM
DETECTOR POSITIONS



CROSS SECTION

Figure 9-2 Detector Locations

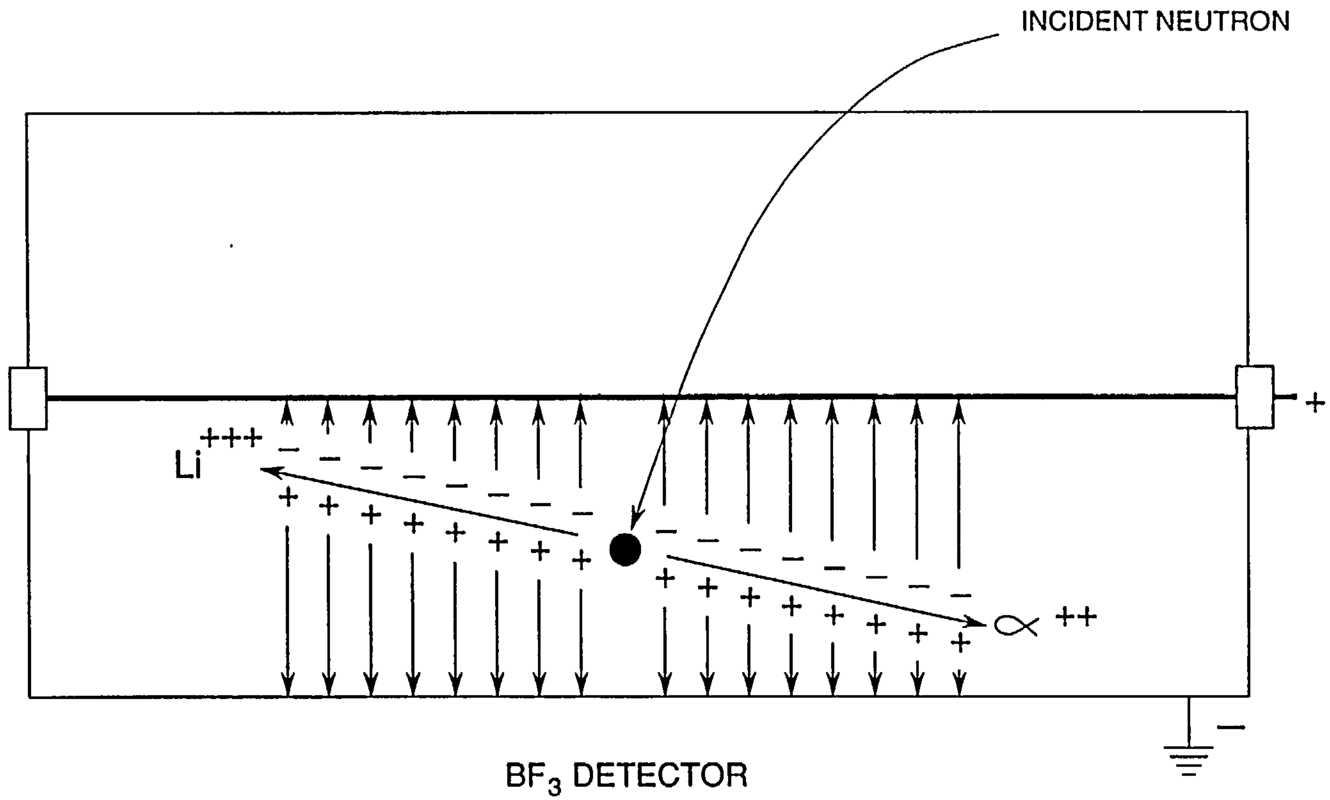
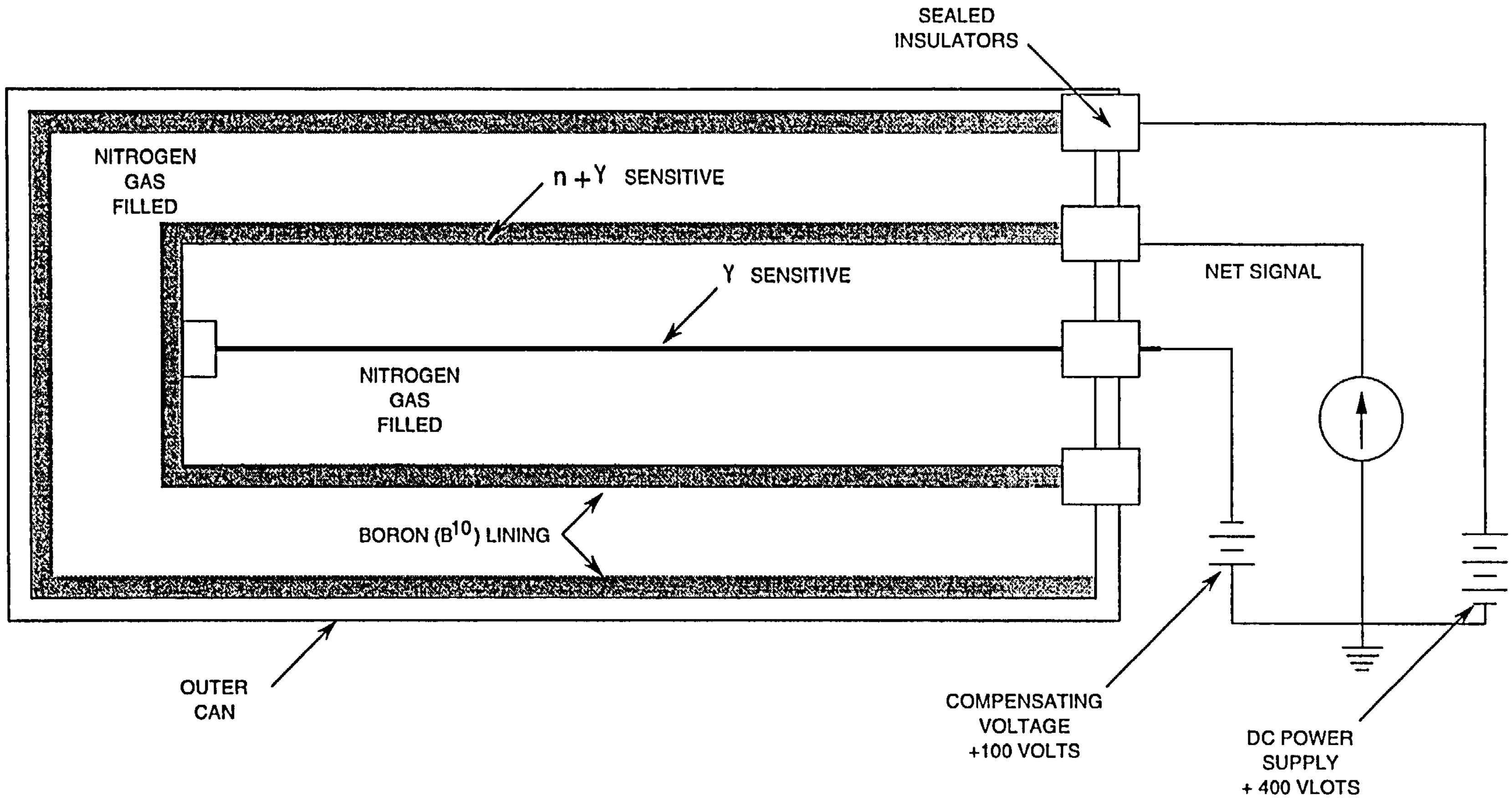
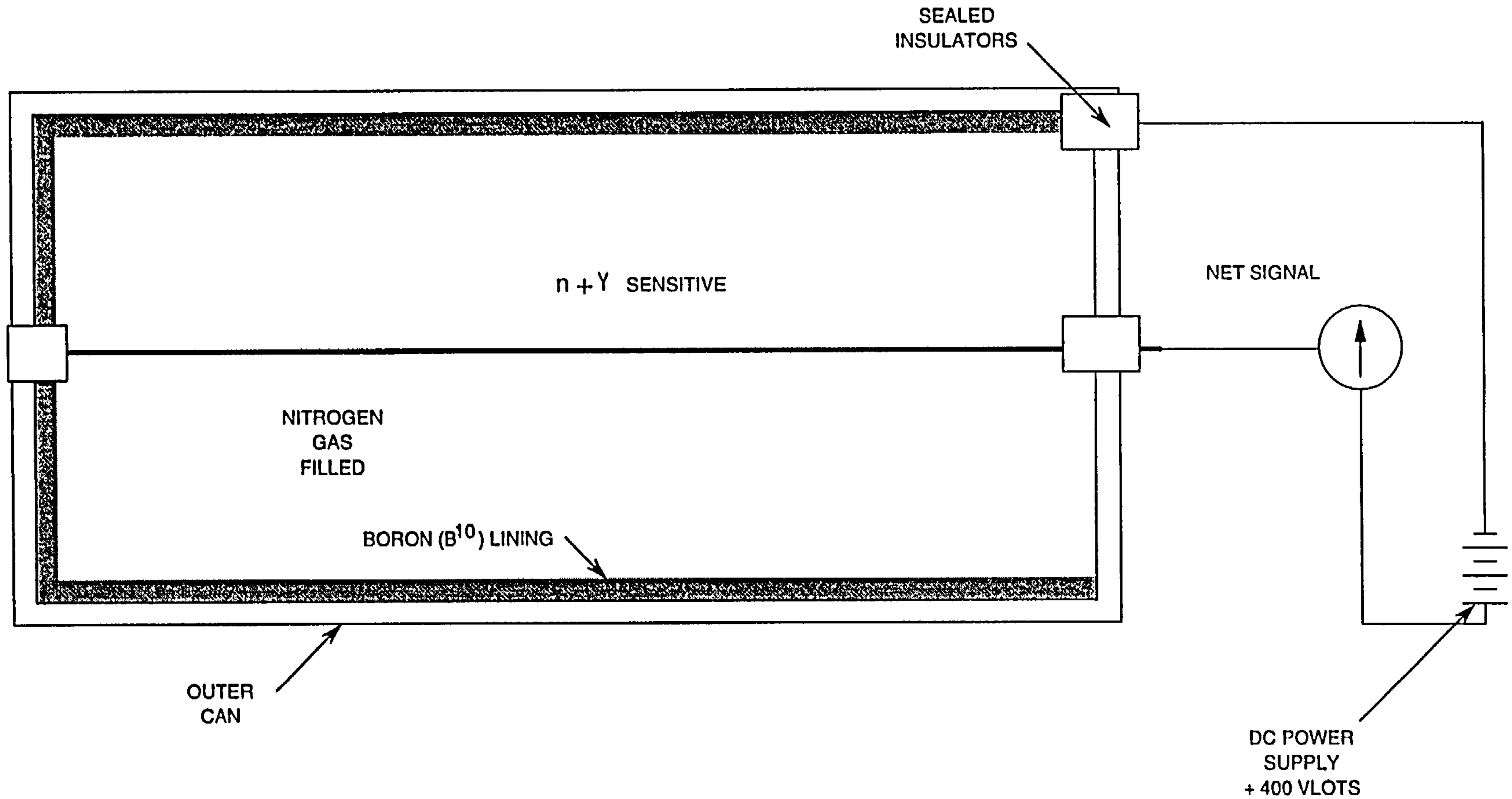


Figure 9-3 Source Range Detector



COMPENSATED ION CHAMBER
(CIC)

Figure 9-4 Intermediate Range Detector



UNCOMPENSATED ION CHAMBER
(UIC)

Figure 9-5 Power Range Detector

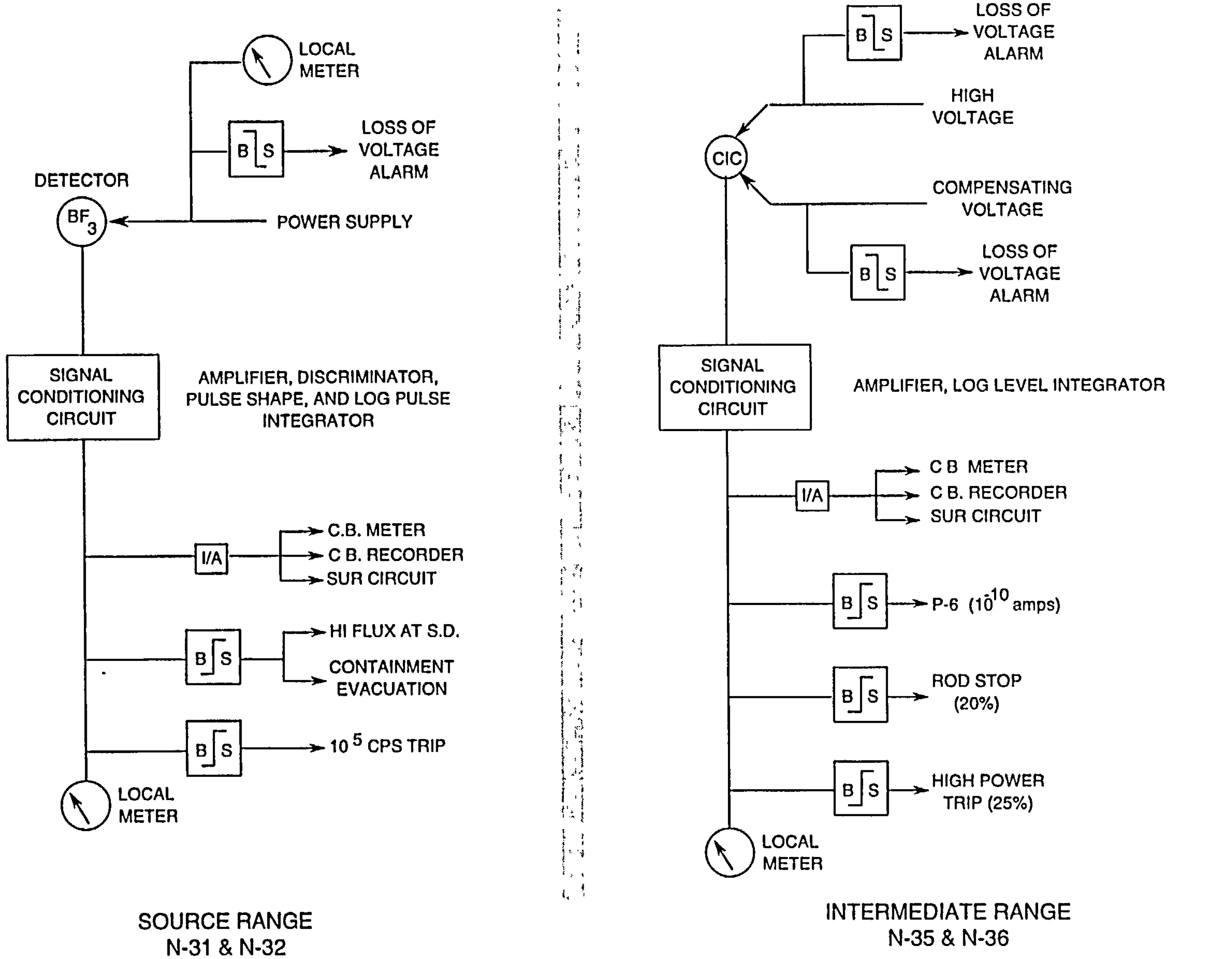
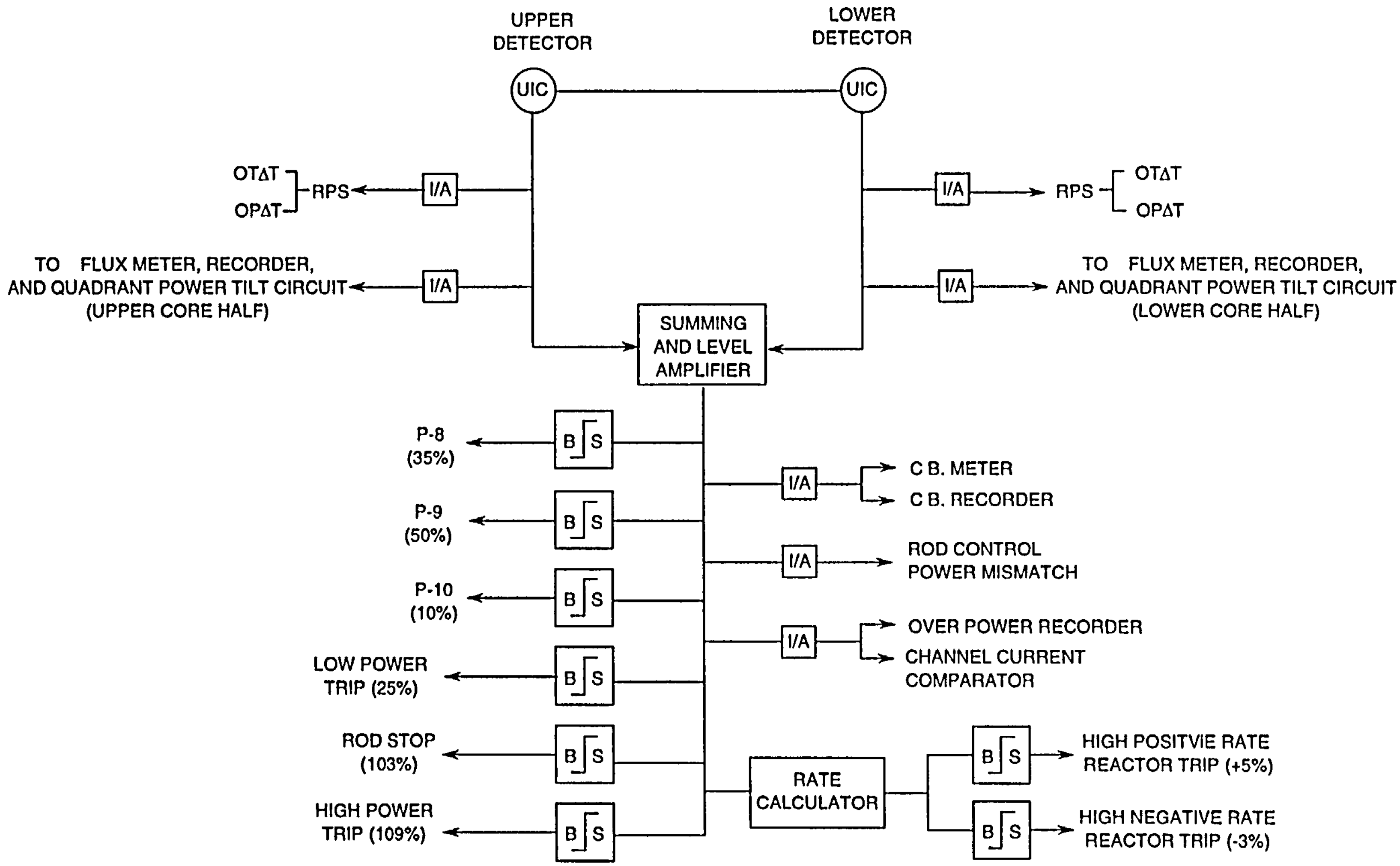


Figure 9-6 Source and Intermediate Range Block Diagrams



POWER RANGE CHANNELS
N-41, 42, 43,& 44

Figure 9-7 Power Range Channel

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Section 10.1

Reactor Coolant System Instrumentation

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10.1 REACTOR COOLANT SYSTEM INSTRUMENTATION

Learning Objectives:

1. List three protection signals described in this chapter.
2. List two systems which respond to the auctioneered T_{avg} signal.
3. State the basis for the low flow reactor trip.
4. State the basis for the OTΔT and OPΔT trips.

10.1.1 Overview

Temperature indication provided by the reactor coolant system temperature instrumentation system is divided into wide range and narrow range indicators. The wide range reactor coolant loop temperature indication provides redundancy to the narrow range indication during operation at power. The indicating range of the wide range instruments also allows temperature indication during heatup and cooldown operations.

The narrow range temperature indication provides high accuracy and fast responding indication of average loop temperature (T_{avg}) and hot leg (T_h) minus cold leg (T_c) temperature difference (ΔT); where Th - Tc = ΔT. Average loop temperature and loop temperature differences are necessary parameters to monitor as they provide input signals for various reactor control and protection functions.

The narrow and wide range temperature indication is provided by resistance temperature detectors, located in wells which extend into the reactor coolant loops (Figure 10.1-1). The wide range resistance temperature detectors (RTDs) provide temperature information for indication, and the narrow range instruments provide temperature inputs for indication, protection, and control rod movement, pressurizer level control, and steam dump operation. Figure 10.1-2 shows the relative locations of the temperature detectors in the reactor coolant system.

10.1.2 RTD Operation

The temperature of the reactor coolant loop hot legs and cold legs is sensed by RTDs. The location of these RTDs in the reactor coolant loops is described in Chapter 3.0. An RTD is a device which uses a length of platinum or nickel wire, which changes in resistance with temperature in a predictable and repeatable manner. Platinum is generally used, because it is the most accurate where temperatures may exceed 500°F. This wire is mounted and sealed in a sheath in such a way that it is in good thermal contact, yet electrically insulated and protected from the process environment. Unless specifically fast measurement time response is necessary, the assembled RTD is inserted into a well which protrudes into the process field. Where fast measurement time response is necessary, the RTDs are in direct contact with the process fluid.

The measurement of temperature with an RTD is reduced to the measurement of resistance (Figure 10.1-1). This is done by supplying a small, highly stable current to a resistance bridge circuit. The RTD is one leg of the bridge circuit. The voltage unbalance across the bridge varies with the resistance of the RTD. This voltage unbalance is measured and amplified to create an analog signal proportional to the temperature at the RTD.

10.1.2.1 Wide Range RCS Temperature

There are two ranges of RCS temperature monitors. Both ranges use RTDs. Temperature of the hot leg (T_h) and of the cold leg (T_c) of each loop is monitored for indication only by wide range (0 - 700°F) RTDs. This range is necessary for transients and for heatup and cooldown operations. Wide range temperature signals are sent to the core subcooling monitor, the reactor vessel level instrumentation system, and the cold overpressure protection system.

These detectors are mounted in wells which penetrate the coolant piping and are part of the pressure boundary. These RTDs do not come in contact with the reactor coolant.

10.1.2.2 Narrow Range RCS Temperature

The narrow range T_h (530 - 650°F) and T_c (510 - 630°F) temperature detectors are used for reactor control and protection. These are fast-acting (about 4 seconds) well mounted RTDs. The narrow range T_h RTDs are immersed in the reactor coolant via three perforated wells located 120° apart. This ensures that a representative sample of the hot leg temperature is obtained. The narrow range T_c RTDs are mounted in a thermowell located directly downstream of each reactor coolant pump. Only one narrow range thermowell per cold leg is required to get a representative temperature indication due to the mixing of the reactor coolant caused by the reactor coolant pump.

The temperature indication signals from the cold and hot leg RTDs of each loop are used in the process instrumentation to generate a loop average temperature (T_{avg}) signal, which is calculated by the formula $(T_h + T_c)/2$. A loop temperature difference (ΔT) signal is also generated, by the formula $T_h - T_c$. The T_{avg} signal is a measure of the stored thermal energy in the reactor coolant system. The T_{avg} signal is used to generate four protection signals and is used in several reactor control circuits (Figures 10.1-3 and 10.1-5).

The ΔT signal is proportional to the total thermal energy transported by the reactor coolant loop and is, therefore, directly related to reactor power. The ΔT signal is used in two protection circuits and in the rod insertion limit circuit (Figure 10.1-4).

T_{avg} and ΔT are calculated for each coolant loop. All protection circuits using these signals are two of four logic for increased reliability. For example, the OT T trip setpoints must be exceeded in at least 2 of the 4 RCS loops to cause an OTΔT reactor trip. The control circuits use auctioneered high T_{avg} or ΔT also for increased reliability. Using the highest T_{avg} or ΔT is conservative, and if a channel fails low (most probable failure), it will not affect the control system.

10.1.3 RCS Flow Instrument

Flow in each reactor coolant loop is sensed by elbow flow meters located in the piping bend on the reactor coolant pump suction. Three low pressure taps and one high pressure tap form three individual sensors. The elbow flow meter is used to measure the differential pressure between the inside and outside areas in a pipe bend. The force per unit area exerted on the outer pipe wall is greater than the force per unit area exerted on the inner pipe wall due to the additional force from the centripetal acceleration around the bend.

10.1.4 Inputs to the Reactor Protection System

10.1.4.1 Overtemperature ΔT (OTΔT)

OTΔT is a continuously calculated trip setpoint that is designed to protect the reactor core from departure from nucleate boiling (DNB) conditions. Four measured primary plant parameters determine if DNB will occur in the reactor core. They are coolant temperature (T_{avg}), coolant pressure, core power, and coolant flow. Coolant flow through the reactor is assumed to be constant and several reactor trips exist to protect the plant if flow is lost or reduced. The other three parameters are variables and are used to generate the OTΔT trip setpoint.

The overtemperature ΔT trip provides core protection from DNB for all combinations of pressure, power, coolant temperature, and axial power distribution. This is only true if the transient is slow with respect to piping transit delays from the core to the temperature detectors (about four seconds), and pressure is within the range between the high and low pressure reactor trips. This setpoint includes corrections for changes in density and heat capacity of the water with temperature, and dynamic compensation for piping delays from the core to the loop temperature detectors. With normal axial power distribution, this reactor trip limit is always below the core safety limit. If axial peaks are greater than design, as indicated by the difference between top and bottom power range nuclear detectors, the reactor trip setpoint is automatically reduced.

In operation, the setpoint <u>decreases</u> if T_{avg} is high or increasing, or if pressure is low, or if flux distribution is outside a normal band. Thus, the setpoint becomes more conservative as the parameters approach a DNB condition. The setpoint <u>increases</u> or becomes less restrictive when T_{avg} is low or decreasing, or if pressure is high. This setpoint is in units of percent of full power ΔT.

10.1.4.2 Overpower ΔT (OPΔT)

OPΔT is a continuously calculated trip setpoint that protects the reactor core from overpower conditions. The OPΔT reactor trip provides assurance of fuel integrity (no melting) from overpower conditions, limits the required range for OTΔT protection, and provides a backup to the high neutron flux trip. The inputs for the OPΔT setpoint calculation are coolant temperature and core power. The setpoint includes corrections for axial power distribution, changes in density and heat capacity of water with temperature, and dynamic compensation for piping delays from the core to the loop temperature detectors.

In operation, the setpoint <u>decreases</u> if T_{avg} is high or increasing. The setpoint <u>cannot</u> be increased above the nominal setpoint like OTΔT.

10.1.4.3 Low T_{avg} Signal

A low T_{avg} signal is used to generate a feedwater isolation signal after a reactor trip has occurred. The feedwater isolation prevents excessive cooldown of the reactor coolant system, which could add positive reactivity to the core. This signal uses a 2 of 4 logic circuit with a setpoint of 554°F.

10.1.4.4 Low-Low T_{avg} Signal

A low-low T_{avg} signal is used to block the steam dumps if Tavg drops too low. The setpoint is 540°F with a coincidence of 2 of 4. The low-low T_{avg} signal is called permissive P-12. On some Westinghouse plants, the permissive signal P-12 will enable the operator to block the high steamline flow engineered safety features actuation signal.

10.1.4.5 Low Flow Trip Signal

The low flow trip signals are provided to protect the core from DNB following a loss of coolant flow accident. In this condition, there is not enough coolant flow to remove the heat generated by the fuel. This trip is necessary because the ΔT trips do not respond fast enough to ensure adequate core protection for a loss of flow accident.

10.1.5 Inputs to Reactor Control Systems

The four T_{avg} signals from the loop instruments are auctioneered so that the highest signal is used for control purposes. The auctioneer circuit serves several functions. By auctioneering high, the control systems are operating on the most conservative signal. An auctioneer circuit also eliminates control system response to all failures that cause the signal to fail low. Since failing low is, by design, the most common mode of failure, increased control system reliability is assured. Should a loop T_{avg} instrument fail, a manually operated defeat switch will block its input to the auctioneer circuit.

The output from the auctioneer is used in five control circuits (Figure 10.1-5). In the rod control system, T_{avg} is compared with T_{ref} (a load signal) to develop a rod speed and direction signal. In the steam dump control system, T_{avg} is again compared with T_{ref} to generate a deviation signal that controls the opening of the steam dump valves. In the pressurizer level control system, T_{avg} is used to produce a reference level. An output to the reactivity computer, used mainly during testing, allows the calculation of temperature reactivity coefficients. An output to the rod insertion limit circuit is also used.

10.1.6 Temperature Alarms

Temperature alarms are generated to alert the operator to possible problem conditions. Each protection bistable for low or low-low T_{avg} generates a warning alarm and a channel alert when tripped. A T_{avg} deviation alarm is generated when the auctioneered high T_{avg} signal differs by ± 2°F from any of the four loop T_{avg} signals. This warns of an instrument failure or unbalanced heat loads. An alarm for auctioneered high T_{avg} indicates that the auctioneered signal is 3°F above the nominal full load T_{avg} setpoint of 578°F. An auctioneered high T_{avg} - T_{ref} deviation alarm indicates that the two signals differ by ± 3°F.

The ΔT signal generates two outputs to the reactor protection system. The two analog outputs, each protected by isolation amplifiers, are compared against the OTΔT and OPΔT calculated setpoints. When the indicated ΔT becomes larger than the calculated setpoint, a reactor trip occurs. The OTΔT and OPΔT trips are both 2 of 4 coincidence.

The output from each loop ΔT is auctioneered to provide the highest signal for the rod insertion limit (RIL) circuit. Again, a failed signal may be blocked from the auctioneer using a defeat switch. A ΔT deviation alarm is generated when the output of the ΔT auctioneer circuit differs from the input loop ΔT signals by ± 2°F.

10.1.7 Summary

The reactor coolant system temperature instrumentation provides indication of the heat content, power, and reactivity balance of the core. Temperature is measured by RTDs, and the system calculates T_{avg} and ΔT for each reactor coolant system loop. These signals are then used for reactor protection and control.

The output of the T_{avg} instrument is used for the following purposes:

- OTΔT trip setpoint,
- OPΔT trip setpoint,
- Low T_{avg} (554°T) Interlock,
- Low-Low T_{avg} (540°F) Interlock (P-12),
- Rod control,
- Steam dump control,
- Pressurizer level control,
- Rod insertion limit circuit, and
- Various recorders, meters, and alarms.

The output of the ΔT instrument is used for the following purposes:

- OTΔT trip,
- OPΔT trip,
- Rod insertion limit circuit, and
- Various meters and alarms.

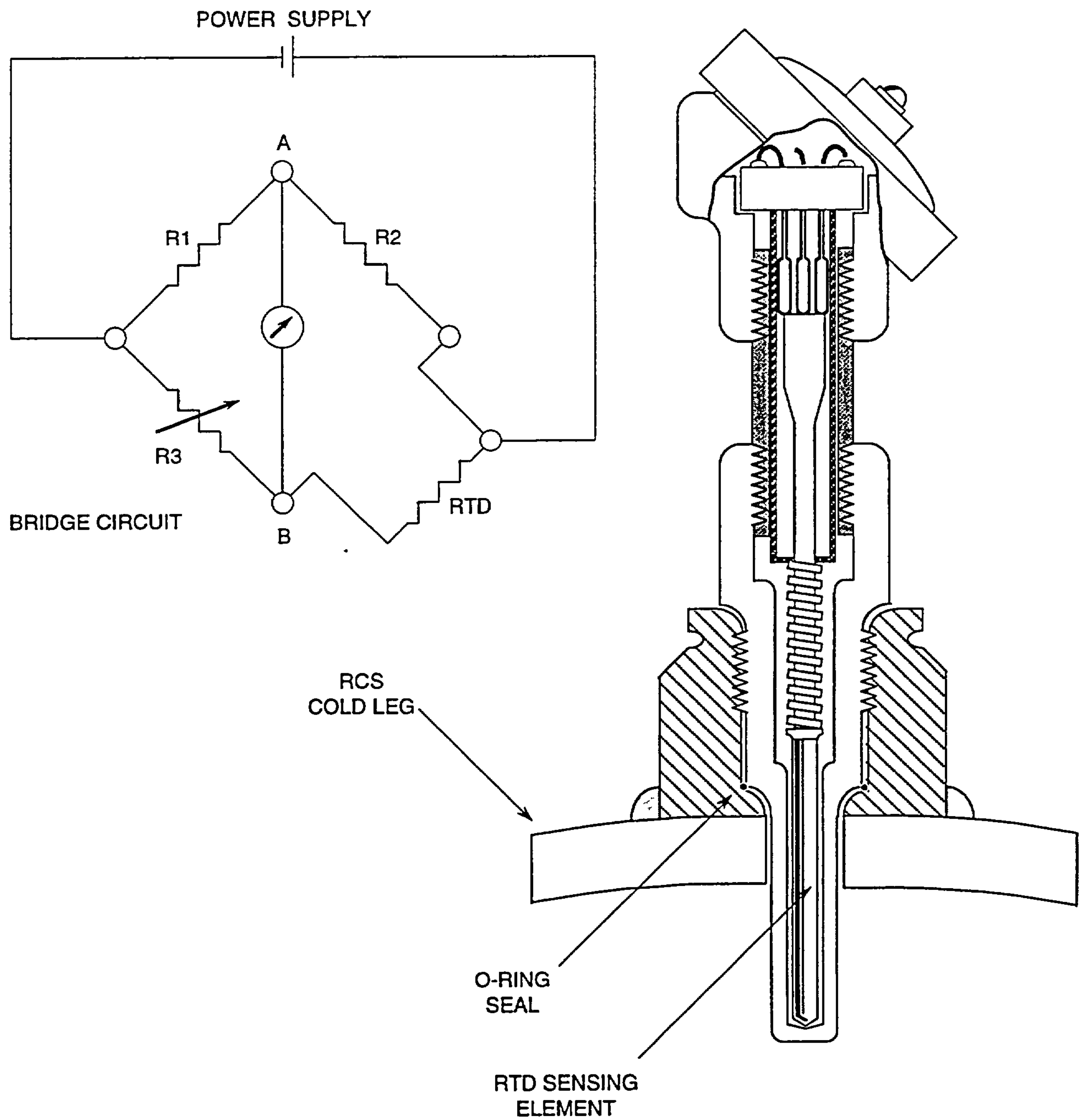

Figure 10.1-1 Resistance Temperature Detector

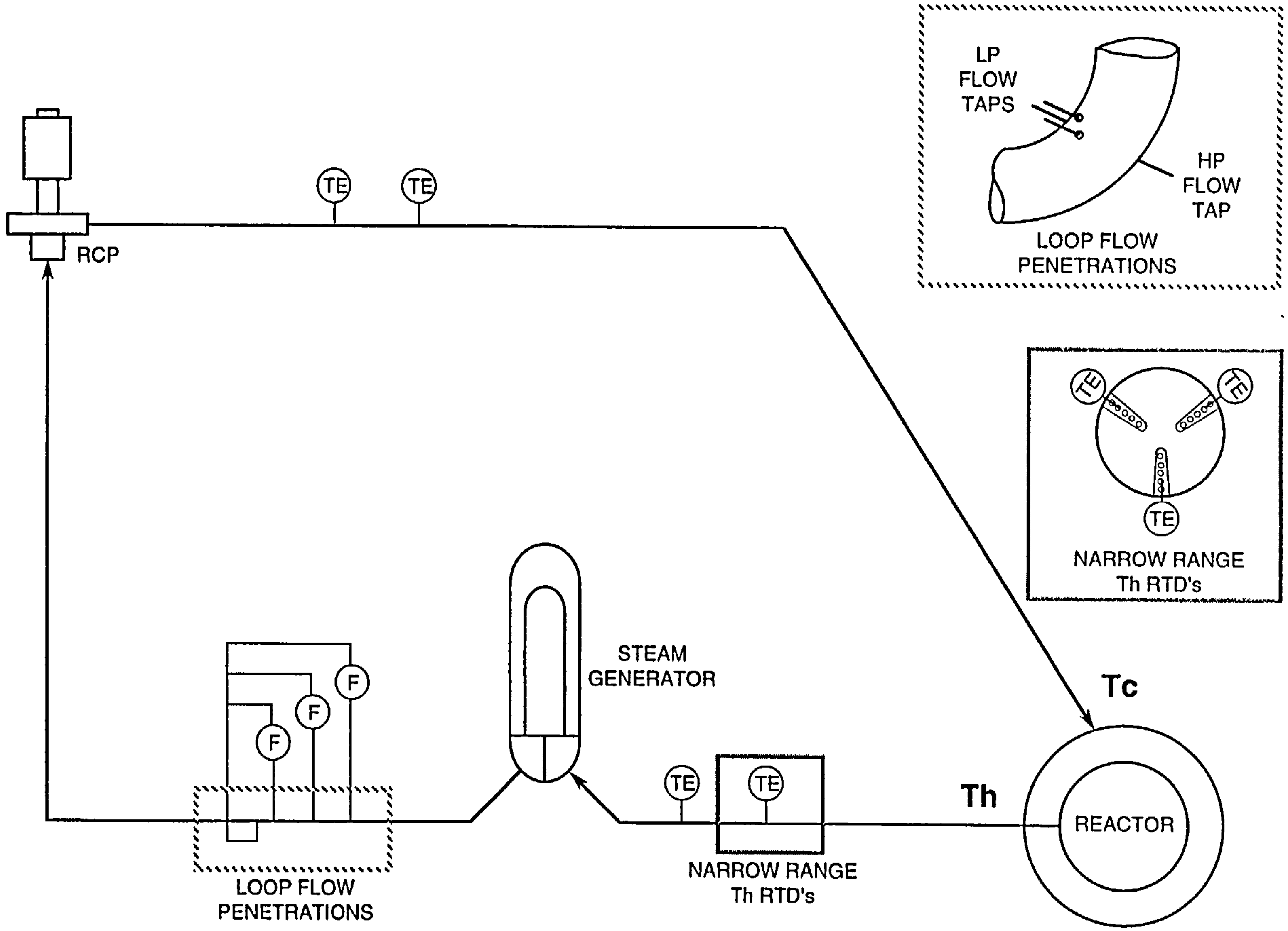

Figure 10.1-2 Reactor Coolant Loop Instrumentation

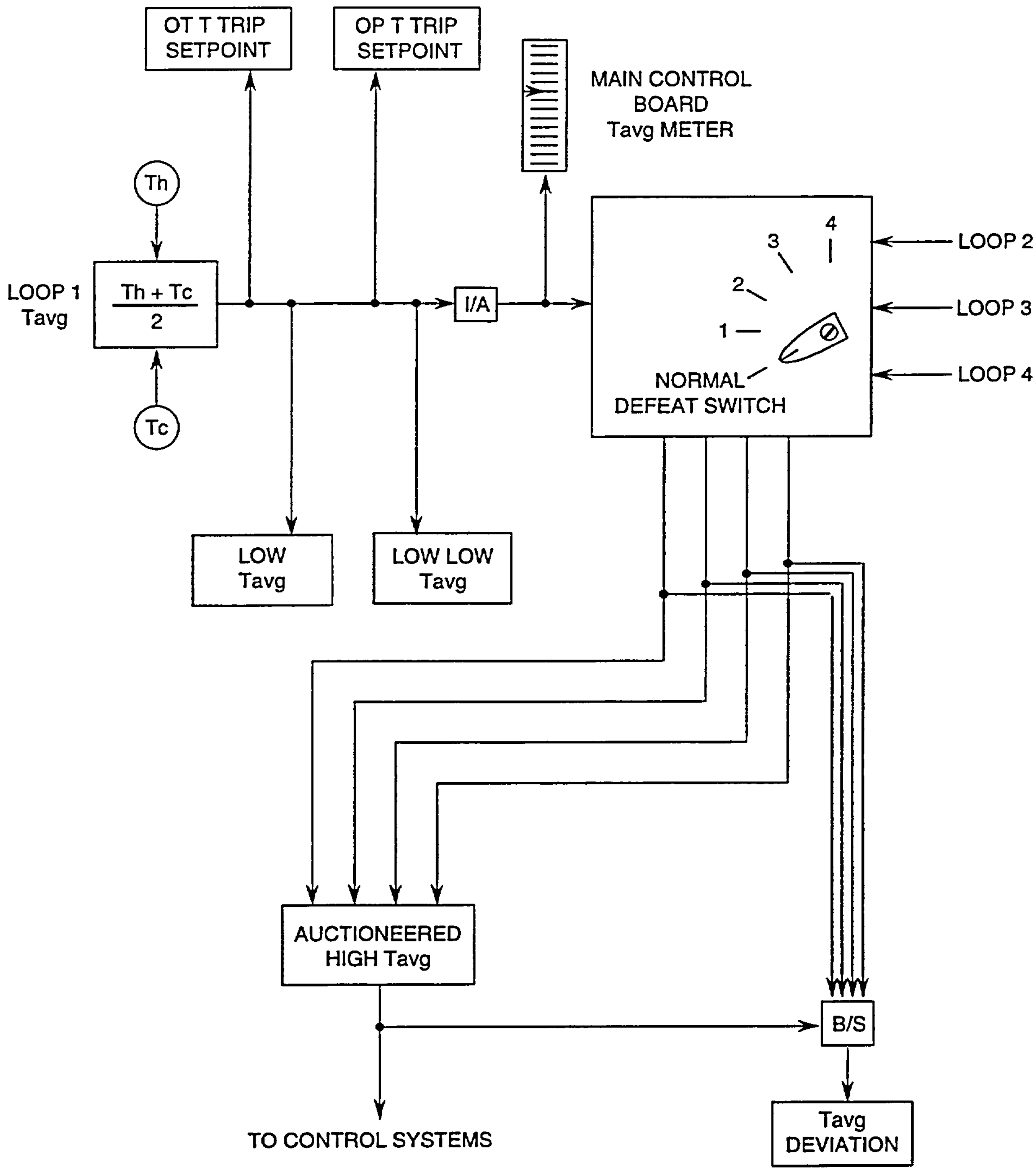

Figure 10.1-3 RCS Average Temperature Instrumentation

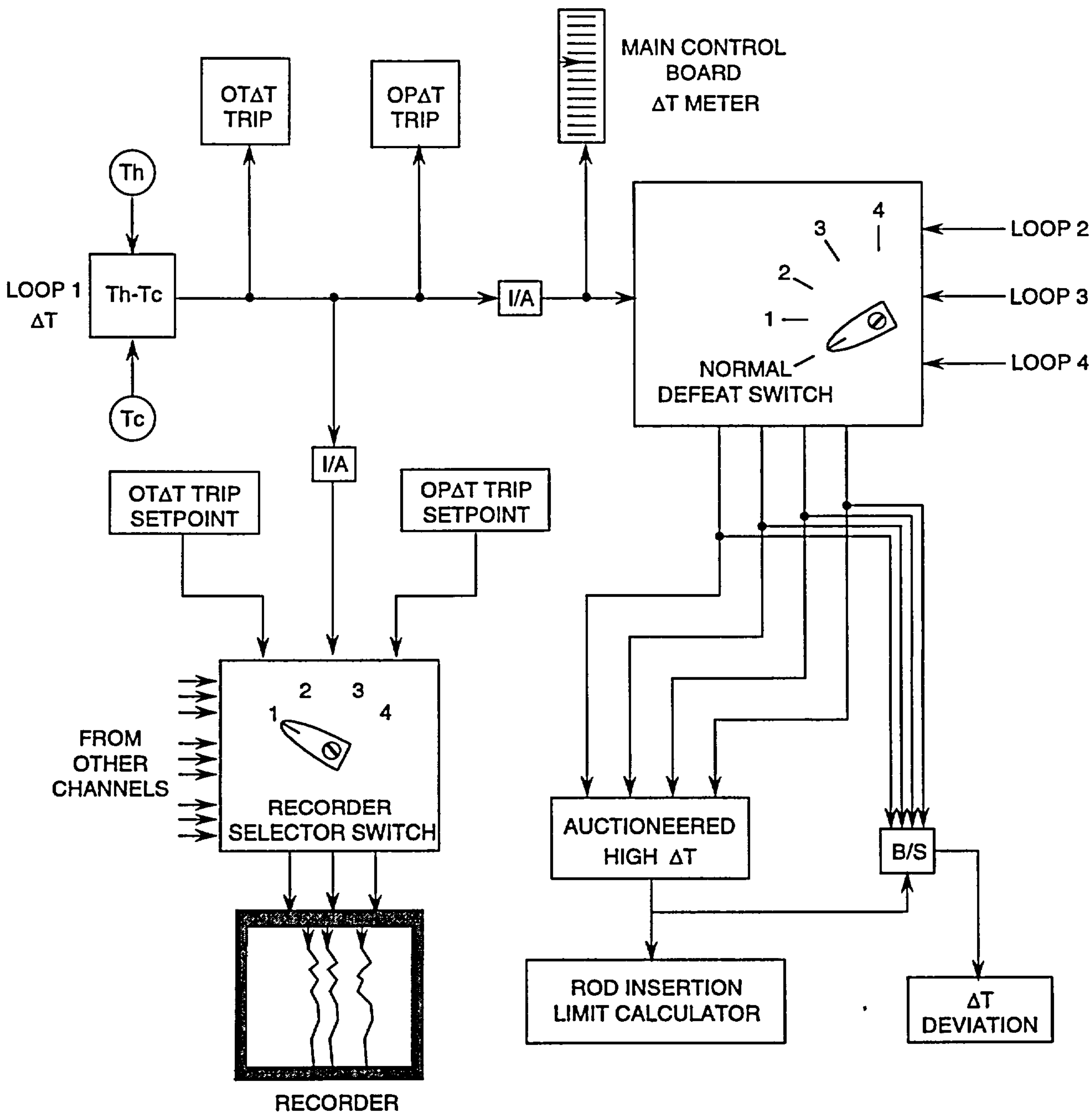

Figure 10.1-4 RCS ΔT Instrumentation

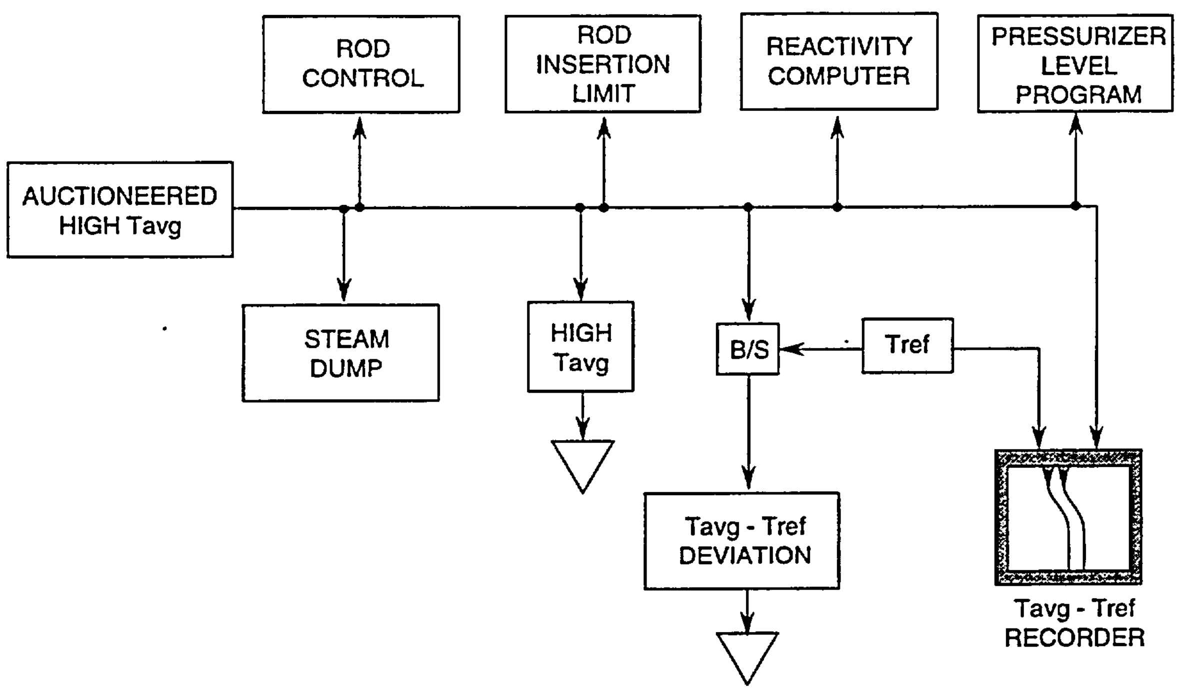

Figure 10.1-5 RCS Auctioneered High Tavg

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Section 10.2

Pressurizer Pressure Control System

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10.2 PRESSURIZER PRESSURE CONTROL

Learning Objectives:

1. State the purpose of the pressurizer pressure control system.

2. List all pressurizer pressure inputs to the reactor protection system and state the purpose of each input.

3. List in order the devices or trips that would actuate to limit or control pressure as reactor coolant system pressure increases from normal system pressure to design system pressure of 2485 psig.

4. List in order the devices or trips that would actuate to limit or control pressure as reactor coolant system pressure is decreased from its normal pressure of 2235 psig.

10.2.1 Introduction

The pressurizer pressure control system maintains the pressure of the reactor coolant system at or near an operator selectable setpoint. This setpoint is normally adjusted to 2235 psig, however, the setpoint is variable between 1700 psig and 2500 psig.

The system is designed to allow the following transients without a reactor trip:

- Loading or unloading at 5 percent per minute with automatic rod control.

- Instantaneous (step) load changes of + or - 10 percent with automatic rod control.

- A step reduction of 50 percent with automatic rod control and the steam dump system operating.

The pressurizer pressure control system utilizes heaters and spray valves to maintain the pressure within an operating band during steady state conditions, and limits the pressure changes during transient conditions. Relief and safety valves provide overpressure protection for the reactor coolant system to ensure system integrity. Various protective reactor trips are generated if system parameters exceed safe bounds.

10.2.2 System Design and Operation

The pressurizer pressure control system (Figure 10.2-1) is provided with four separate sensing channels, each with its own pressure detector and associated circuitry. All four channels supply an input to the reactor protection system trip logic for the following reactor trips:

a. High pressure reactor trip (2/4 logic),

b. Low pressure reactor trip (2/4 logic, rate compensated), and

c. Overtemperature ΔT (a DNB related trip, of which pressure is a major factor in DNB calculations, described in Chapter 12).

In addition to the reactor trip signals, three of the four channels will provide inputs to the low pressurizer pressure block permissive (P-11) and to the low pressurizer pressure engineered safety features (ESF) actuation signal.

To prevent an inadvertent or spurious initiation of an ESF during normal plant cooldown and depressurization, the low pressure ESF may be manually blocked at the main control board. A block permissive (P-11) is actuated when the pressure on 2/3 pressure channels is at a value slightly above (usually 100 psig) the low pressurizer pressure ESF setpoint. The low pressurizer pressure ESF protection is automatically reinstated if pressurizer pressure increases above the block permissive setpoint.

One instrument channel is chosen as the primary control channel. The selected channel pressure signal is passed through a selector switch which allows an alternate channel to be selected if a failure of the normal controlling channel occurs. This pressure signal (actual system pressure) is sent to a summer where it is compared to a manually inserted reference (desired) pressure setpoint (normally 2235 psig). If a deviation occurs between the actual and the reference pressure, an error signal is sent to a controller which will modify the pressure error signal. The following pressure control devices are supplied with this modified signal:

a. Pressurizer variable heaters - This heater bank is supplied a varying input current as a function of the pressure deviation signal. Normally these heaters are energized at half current when pressure is at setpoint (no pressure error). The variable heaters will be deenergized at +15 psig and fully energized at -15 psig from the normal controlling point of 2235 psig.

b. Pressurizer backup heaters - These normally deenergized heater banks turn on if the pressure deviation exceeds -25 psig. They will remain on until the deviation is within -15 psig. They are simply on-off type with no variable control.

c. Pressurizer spray valves - The two spray valve controllers are set to modulate the pressurizer spray valves starting at an error of +25 psig with the valves full open at +75 psig. These valves will operate to prevent lifting the pressurizer relief valves. The reactor coolant system cold leg water admitted through the spray valves is extremely effective in limiting pressure increases during transient or accident conditions.

d. Power operated relief valve - One of the two power operated relief valves receives the modified error signal and will actuate if the error signal reaches +100 psig above reference.

A second control channel is selected as the control signal for the second power operated relief valve. This valve will open when the pressure reaches 2335 psig, or 100 psig above normal. The operation of the power operated relief valves should limit the pressure increase in the pressurizer to prevent a high pressure reactor trip or lifting (opening) the code safety valves.

The third and fourth channels, in addition to their use as backup control channels, provide an opening interlock for the power operated relief valves. If pressure decreases below 2185 psig, the power operated relief valves will be interlocked closed. This prevents a failed control channel from depressurizing the plant by maintaining a relief valve in the open position. This interlock affects only automatic actuation of the reliefs, with manual operation (from the control board) still available if needed. Pressure indication from all four channels, plus a recorder with four-position selector switch, is provided on the main control board.

In addition to the control device setpoints, various alarms and protection setpoints are shown on Figure 10.2-2.

10.2.3 Summary

The pressurizer pressure control system maintains the reactor coolant system pressure at or near 2235 psig. The system uses heaters, spray valves, and relief valves which are actuated when actual pressure deviates from 2235 psig. In addition to controlling pressure, signals from the pressure instruments are sent to the reactor protection system for such protective functions as trips, ESF initiations, and interlocks.

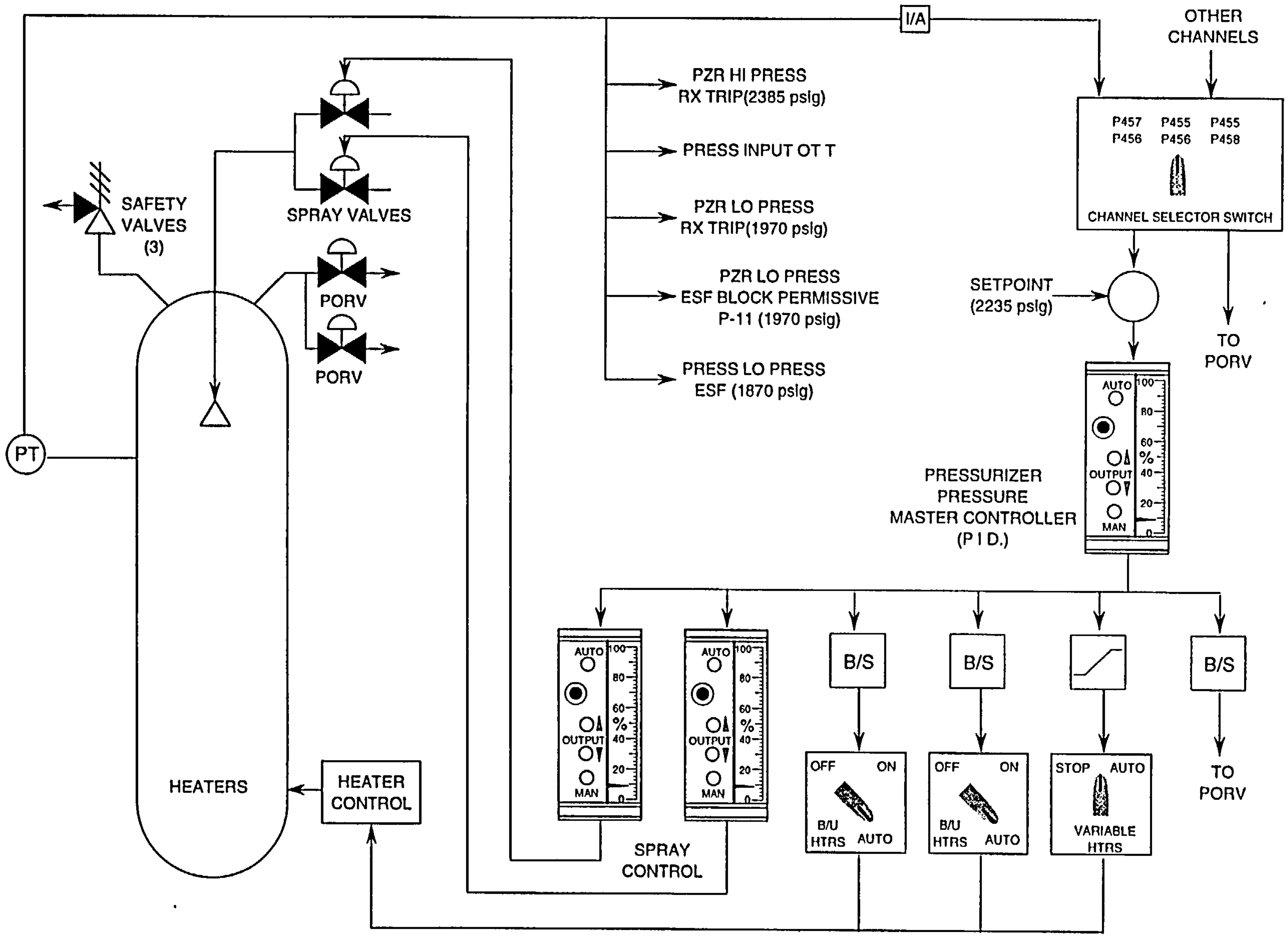

Figure 10.2-1 Pressurizer Pressure Control

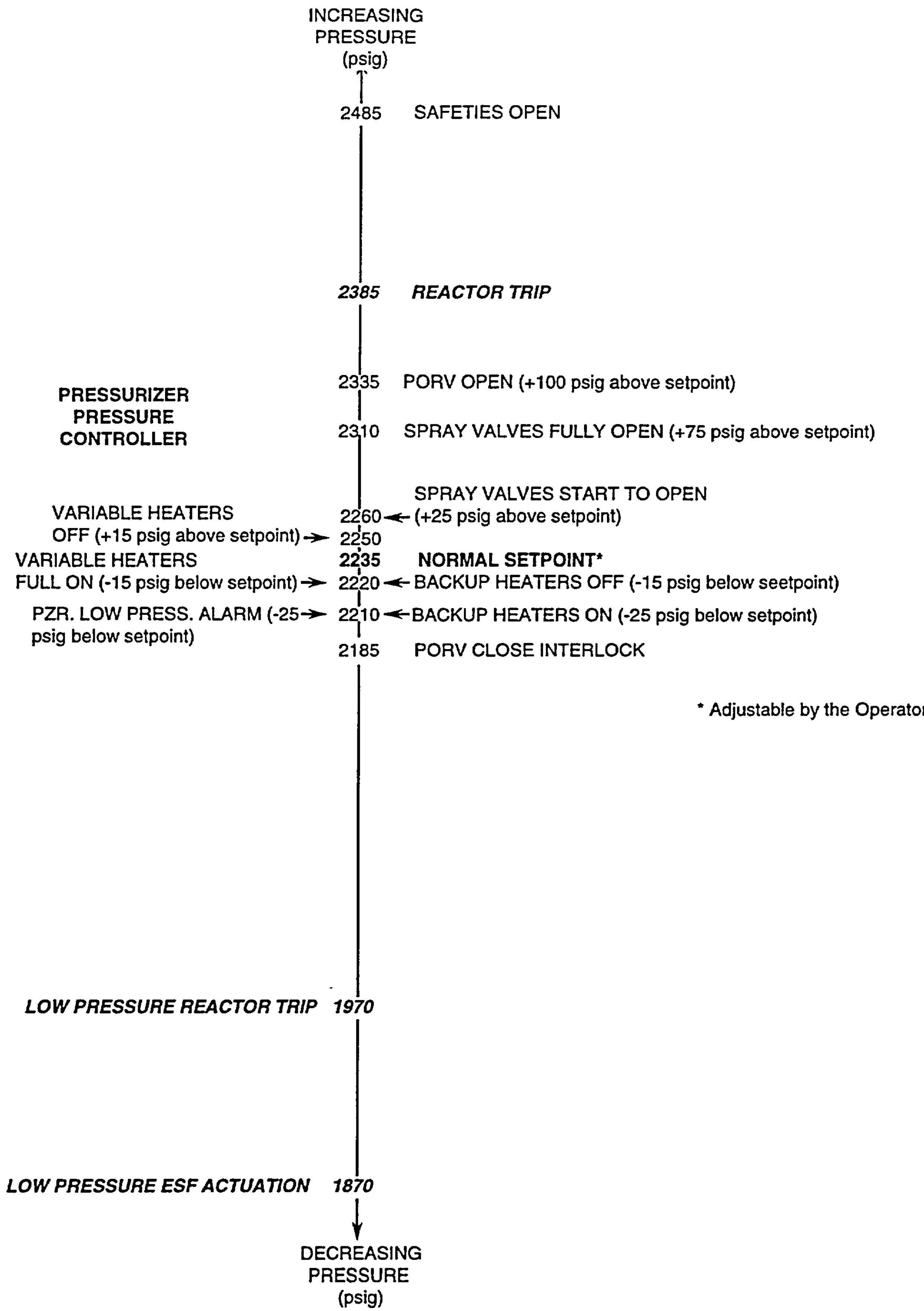

Figure 10.2-2 RCS Pressure Setpoint Diagram

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Section 10.3

Pressurizer Level Control System

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10.3 PRESSURIZER LEVEL CONTROL

Learning Objectives:

1. State the purpose of the pressurizer level control system.

2. State the purpose of the pressurizer level input to the reactor protection system.

3. Identify the signal that is used to generate the "reference level" and explain why level is programmed.

4. Describe the components used to change charging flow in response to level error signals.

5. State the purpose and describe the function of the pressurizer low level interlock.

10.3.1 Introduction

The pressurizer level control system controls the water level in the pressurizer as a function of the average reactor coolant temperature. By controlling the level in the pressurizer, primary system water inventory in maintained. Level control is accomplished by controlling the balance between water leaving the reactor coolant system (letdown) and water entering the reactor coolant system (charging). Since letdown flow is fixed, pressurizer level is maintained at program by varying the charging flow. The positive displacement pump speed is changed to change charging flow, while centrifugal charging pump flow is varied by adjusting a discharge throttle valve.

Reactor coolant system average temperature (T_{avg}) changes, resulting from reactor power or turbine load variations, will cause a pressurizer level change due to the density change of the reactor coolant. To minimize the effects of these level changes, the pressurizer level is programmed as a function of reactor coolant system temperature. Since T_{avg} is programmed to increase as the power level is increased, pressurizer level will increase with the power level to match the expansion characteristics of the reactor coolant.

This minimizes the charging flow changes. However, fast transient load changes will create an imbalance requiring charging flow adjustments.

In addition to supplying signals for control and indication, the level indicators provide a signal to the reactor protection system for the high level reactor trip.

10.3.2 System Design and Operation

The pressurizer level control system (Figure 10.3-1) is provided with three hot-calibrated channels. A fourth channel (not shown) is cold-calibrated and is used for indication only. The hot-calibrated channels supply an input to the reactor protection system for the high pressurizer level reactor trip (2/3 logic).

The high level reactor trip is provided to remove the source of heat (the core at power) if the pressurizer becomes completely full of water. A pressurizer full of water (water solid) offers no means of controlling pressure in the reactor coolant system. Water solid conditions could result in pressure changes of 100 psi or more for each 1°F T_{avg} change.

One channel is selected as the control channel. The control channel signal is passed through a channel selector switch which allows an alternate channel to be selected if a failure of the normal controlling channel occurs.

The actual level signal from the controlling channel is supplied to a summer where it is compared to pressurizer reference level. If there is a deviation between these signals (actual level to reference level), a level error output signal is passed through a controller to change the charging flow. If the positive displacement charging pump is running, the controller changes the pump speed which changes the flow rate. If a centrifugal charging pump is running, flow is controlled by adjusting a flow control valve on the discharge of the pumps.

The reference (or setpoint) level is derived from auctioneered high T_{avg}. Since T_{avg} changes with plant load (547°F at no-load to 577°F at full load), the water volume in the pressurizer also changes due to the change in water density in the reactor coolant system. This change in level due to a temperature change in not a change in reactor coolant system inventory. By programming the reference level as a function of T_{avg}, almost no level control system action will be required over the full range of power operations (Figure 10.3-2).

If pressurizer level decreases below the low pressurizer level interlock (17%), letdown is isolated to the chemical and volume control system, and the pressurizer heaters are turned off. The letdown isolation is an attempt to stop or slow the loss of water out of the reactor coolant system. Turning off the heaters protects them from burning out if they are uncovered.

Generally, during plant load change conditions, an outsurge of water from the pressurizer will result in a pressure decrease and an insurge will result in a pressure increase. However, if the insurge is large enough, it will eventually result in a system pressure decrease due to the fact that the insurge water is at a lower temperature than water in the pressurizer, which is at saturation. Therefore, if pressurizer level increases above the program level setpoint by five percent, the control system will automatically energize the backup heaters in an effort to limit the expected pressure drop.

10.3.3 Summary

The pressurizer level control system maintains the water inventory of the reactor coolant system by varying the charging rate. In addition, there are provisions to isolate letdown and turn off heaters on low level to minimize the effects of a loss of coolant or coolant leak ant to protect the pressurizer heaters. The system will also turn on the pressurizer heaters on a level higher than program to anticipate a pressure decrease. Program or reference level is derived from auctioneered T_{avg} and is compared to actual level to produce level error. Level error is the signal sent to the charging system to change the charging rate.

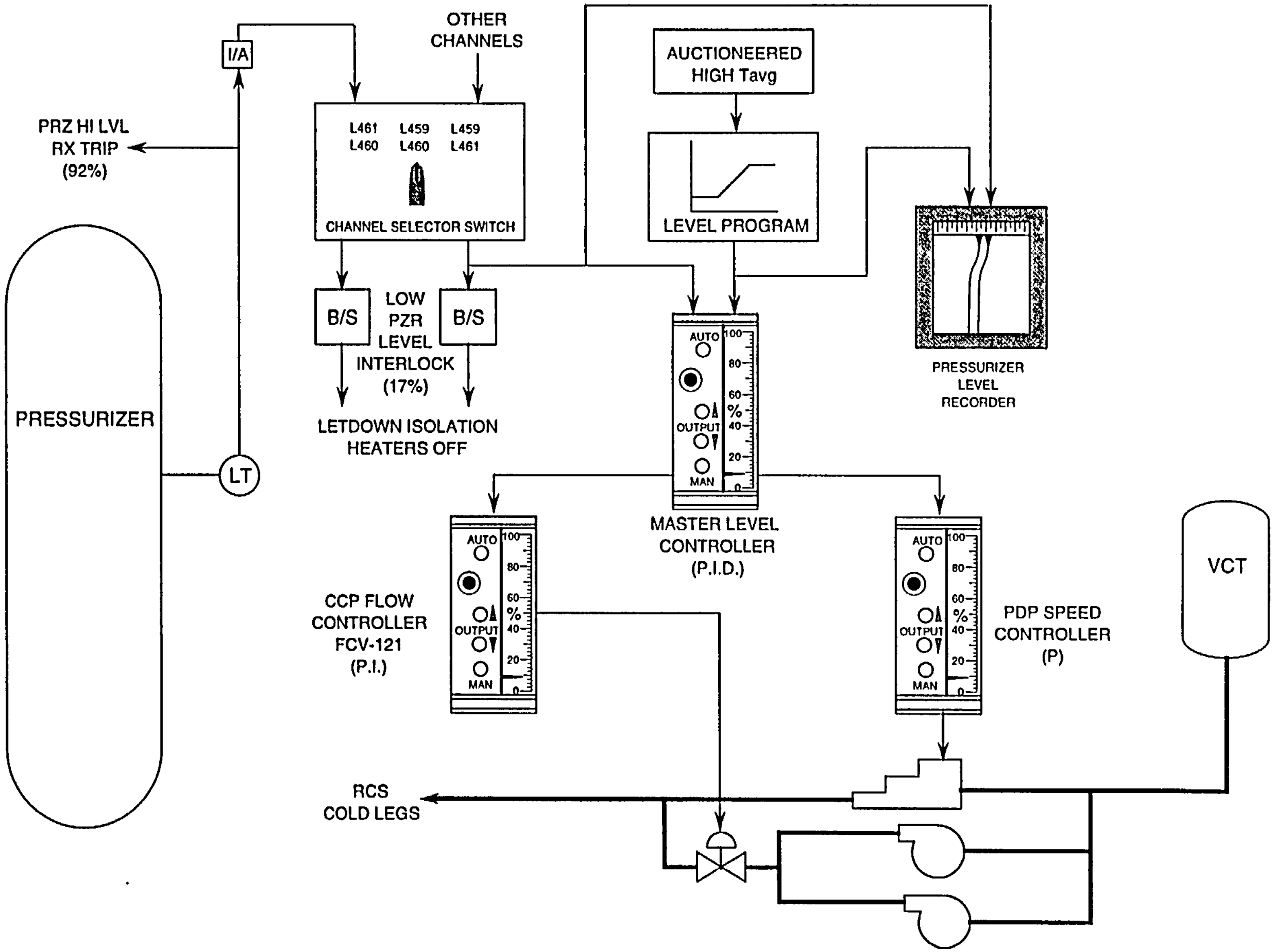

Figure 10.3-1 Pressurizer Level Control

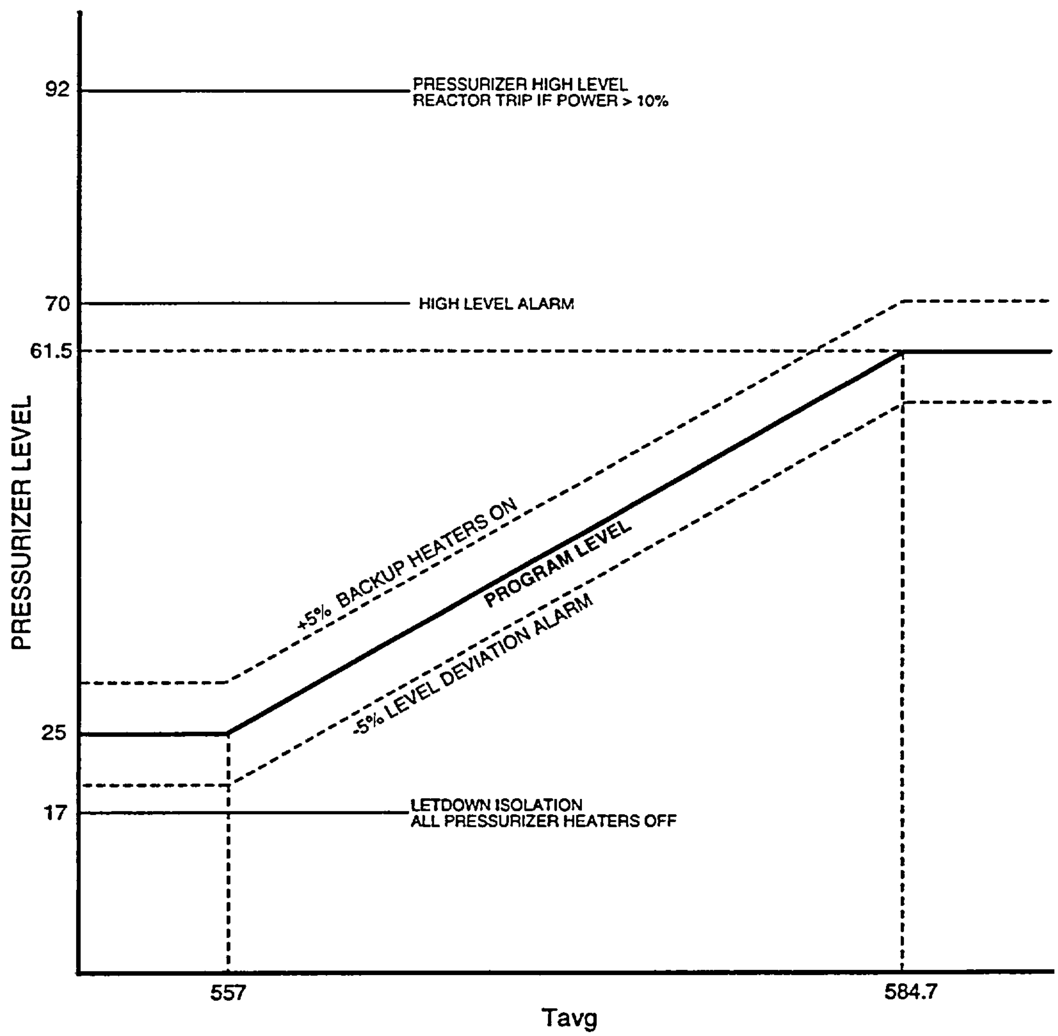

Figure 10.3-2 Pressurizer Level Program